# Thermal and Environmental Assessment of Post Tsunami Housing in Banda Aceh, Indonesia

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# ABSTRACT

This research aims to assess the conditions in houses built for Tsunami victims in Banda Aceh, Indonesia with respect to sustainability issues. As this is a major issue in providing comfortable and satisfying settlements, post-tsunami housing needs to be treated from the perspective of sustainability as well. In this study, assessments were carried out on some issues such as house designs, including house materials and house construction; thermal comfort; lighting provisions; acoustic performance; health considerations; surrounding environment; waste treatment and general energy performance. The survey which included interviews, questionnaires and measurement using mechanical equipment was carried out from May 11$^{th}$ to July 19$^{th}$ 2009. 208 houses were surveyed to complete this study. TAS building modelling software was also utilised to analyse the indoor thermal performance in post tsunami housing. The overall results of the study show that post-tsunami housing is still built conventionally. It seems that there has been no integration between housing construction and house maintenance, especially to support the occupation stage, such as power and water supply; treatment of waste, etc. The study also shows that there is no significant difference in inside air temperature between the post-tsunami houses and the unaffected existing houses (except traditional Acehnese houses). The inside air temperature values stand higher than the neutral temperature applicable in Indonesia, whereas the thermal value in the Acehnese traditional house is closer to the neutral temperature. This confirms that the post-tsunami housing was built similarly to currently typical houses in Aceh. At the last stage, this study provides some recommendations for good house design for the tsunami disaster victims which considers the local climate and sustainability issues; and alternative house designs applying the recommendations responding to thermal building design in the tropics.

# Dedication

I Dedicate this work for my beloved parents, husband and children;

and my country Indonesia

# ACKNOWLEDGEMENT

All praise is due to Allah and peace be upon the prophet Muhammad SAW

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# ACRONYMS AND GLOSSARY OF SYMBOLS

| | | |
|---|---|---|
| ADB | : | Asian Development Bank |
| ASHRAE | : | American Society of Heating, Refrigeration, and Air-Conditioning Engineers |
| Bapedalda | : | Badan Pengendalian Dampak Lingkungan Daerah (Regional Environmental Impact Management Agency) |
| BAPPENAS | : | National Development planning Agency |
| Bataton | : | Bata beton (concrete brick) |
| BPPK | : | Badan Pendidikan dan Pelatihan Keuangan (Financial Training Agency) |
| BMG | : | Badan Meteorologi dan Geofisika Indonesia |
| BRE | : | Building Research Establishment |
| BREEAM | : | Building Research Establishment Environmental Assessment Method |
| BRR | : | Badan Rehabilitasi dan Rekonstruksi |
| CEBs | : | Compressed Earth Blocks |
| CFD | : | Computational Fluid Dynamics |
| CIBSE | : | Chartered Institute of Building Services Engineers |
| CRS | : | Catholic Relief Services |
| EDSL | : | Environmental Design Solutions Limited |
| FAO | : | Food and Agriculture Organisation |
| GAM | : | Gerakan Aceh Merdeka (Free Aceh Movement) |
| GITEC | : | Government information technology Executive. Council |
| GRC | : | Glass Reinforced Concrete |
| GTZ | : | The Deutsche Gesellschaft für Technische Zusammenarbeit |
| Huntara | : | Hunian Sementara (temporary shelter) |
| IDR | : | Indonesian Rupiah |
| IEQ | : | indoor environmental quality |

IISBE : International Initiative for a Sustainable Built Environment

ILO : International Labour Organization

IOM : International Organization for Migration

LED : Light Emitting Diode

MPW : Ministry of Public Works

NAD : Nanggroe Aceh Darussalam

NGO : Non Governemental Organization

OXFAM : Oxford Committee for Famine Relief

ODR : Owner Driven Rehabilitation

P2KP : Percepatan Penganekaragaman Konsumsi Pangan (Food Consumption Diversification Acceleration)

PERKIM : Perumahan dan permukiman

PKPU : Pos Keadilan Peduli Umat (National Humanitarian Foundation)

PMV : Predicted Mean Vote

PMI : Palang Merah Indonesia (Indonesian Red Cross)

PPD : Predicted percentage dissatisfied

Ppm : Parts per million (unit of $CO_2$ contamination)

PU : Pekerjaan Umum (Ministry of Public Works)

SBS : Sick Building Syndrome

SLGSR : Support for Local Governance for Sustainable Reconstruction

SNI : Standard Nasional Indonesia (Indonesian National Standard)

TAS : Thermal Analysis Simulation

UNCSD : United Nations Conference on Sustainable Development

UNDP : United Nations Development Programme

UNEP : United Nation Environmental Program

UNESCO : United Nations Educational, Scientific and Cultural Organization

UN Habitat : The United Nations Human Settlements Programme

| | |
|---|---|
| Unsyiah | : Universitas Syiah Kuala |
| Uplink | : Urban Poor Linkage |
| WHO | : World Health Organization |
| YBI | : Yayasan Berkati Indonesia |
| a | : Air change rate (air changes per hour) |
| A | : Component area ($m^2$) |
| $c_p$ | : Specific heat capacity of air at constant pressure, for which the value 1012 J/kgK is taken |
| $h^{int}$ | : Convective heat transfer coefficient ($W/m^2K$) |
| $m^{inf}$ | : Infiltration air mass flow rate (kg/s) |
| $Q^{inf}$ | : Sensible heat gain due to infiltration (Watts) |
| RH | : Relative humidity (%) |
| $T^{ext}$ | : External surface temperature ($^0C$) |
| Tco | : Comfort temperature($^0C$) |
| Tm | : Mean monthly outdoor temperature($^0C$) |
| $T_{rm}$ | : Exponentially weighted running mean temperature($^0C$) |
| $T^{int}$ | : Temperature on the internal surfaces ($^0C$) |
| $T^{ext}$ | : Temperature on the external surfaces ($^0C$) |
| $T_o^{air}$ | : Outside air temperature ($^0C$) |
| $\Delta T$ | : Absolute temperature difference (K) between the room air (temperature $T^{air}$) and the surface (temperature $T^{int}$) |
| V | : Volume of air in the zone ($m^3$) |
| $v_m$ (m/s) | : Wind speed measured at the meteorological station at a height of 10m |
| $W^{cond, int}$ | : Internal surface conduction heat flux ($W/m^2$) |

| | |
|---|---|
| $W^{cond, int}$ | : Internal surface conduction heat flux ($W/m^2$) |
| $W^{cond, ext}$ | : External surface conduction heat flux ($W/m^2$) |
| $\varepsilon^{ext}$ | : Emissivity of the surface |
| $\Theta^{ext}$ | : Absolute temperature of the surface (K) |
| $\rho^{air}$ | : 1.210 $Kg/m^3$(the density of air at standard atmospheric pressure and a temperature of 20C) |

# PUBLISHED PAPERS

**The following papers have been published as a result of this research:**

**Sari, L.H.**, Harris, D. and Gormley, M., (2010) 'Assessment of Comfort in Ten Types of Post Tsunami House in Banda Aceh, Indonesia', *Proceedings of Conference: Adapting to Change: New Thinking on Comfort*, Cumberland Lodge, Windsor, UK, 9-11 April [online]. Available from: http://nceub.commoncense.info/uploads//02-01-17-Sari.pdf

**Sari, L.H.**, Harris, D. and Gormley, M., (2010) 'Thermal and Environmental Assessment Of Post-Tsunami Housing In Banda Aceh, Indonesia', *Proceedings of Conference: 9th International Detail Design in Architecture,* University of Central Lancashire Preston, UK PR1 2HE. 4th & 5th November (awarded as the best paper prize by the international Journal of Construction Innovation, see: http://www.uclan.ac.uk/schools/built_natural_environment/detail_design_conference_report.php)

**The following papers (as a result of this research) are in the process of submission to Emerald journal:**

**Sari, L.H.**, Harris, D. and Gormley, M., *Indoor Thermal Assessment of Post Tsunami-Housing in Banda Aceh, Indonesia*, A paper being submitted to Journal of Construction Innovation, Emerald

**Sari, L.H.**, Harris, D. and Gormley, M., *Environmental Evaluation of Post Tsunami-Housing in Banda Aceh Indonesia,* A paper being submitted to Journal of Construction Innovation, Emerald

# CHAPTER 1 – INTRODUCTION

## 1.1 Background

Aceh, the northern part of Sumatra in Indonesia, is one of the places affected most by the 9.2 Richter scale earth quake that took place on December 26, 2004 and was directly followed by a tsunami (Steinberg, 2007). It was massively destructive and had a huge influence on the surrounding environment (figure 1.1). Banda Aceh as the capital city of Aceh (NAD) province suffered quite heavy destruction as shown table 1.1

**a.**  **b.** 

Figure 1.1 Banda Aceh before (a) and after (b) tsunami
(Source: http://www.peterloud.co.uk/indonesia/tsunami.html)

Table 1.1 Tsunami destruction in Banda Aceh city

| | | |
|---|---|---|
| **Affected area** | 6 sub districts are damaged. | |
| | 3 others are not affected at all | |
| **Tsunami's effect to population (persons)** | Before: | 264,618 |
| | Death: | 61,065 |
| | After: | 203,553 |
| **Damaged houses (units)** | Heavy damaged: | 17,219 |
| | Medium damaged: | 4.193 |
| | Total: | 21,412 |
| **School Buildings (units)** | Good: | 110 |
| | Damaged: | 56 |
| | Destroyed: | 119 |

Source: Nurdin (2006)

Dealing with this huge rehabilitation, hundreds of national and international aid agencies from more than 130 countries contributed to a massive emergency aid programme (UNEP, 2007). The emergency aid came to the peak level within year 2005. Thereafter housing was emphasized to shelter the victims followed by infrastructure and livelihoods in 2006, and in subsequent years to longer term infrastructure needs and local capacity building (BRR and International Partners, 2005) [figure 1.2].

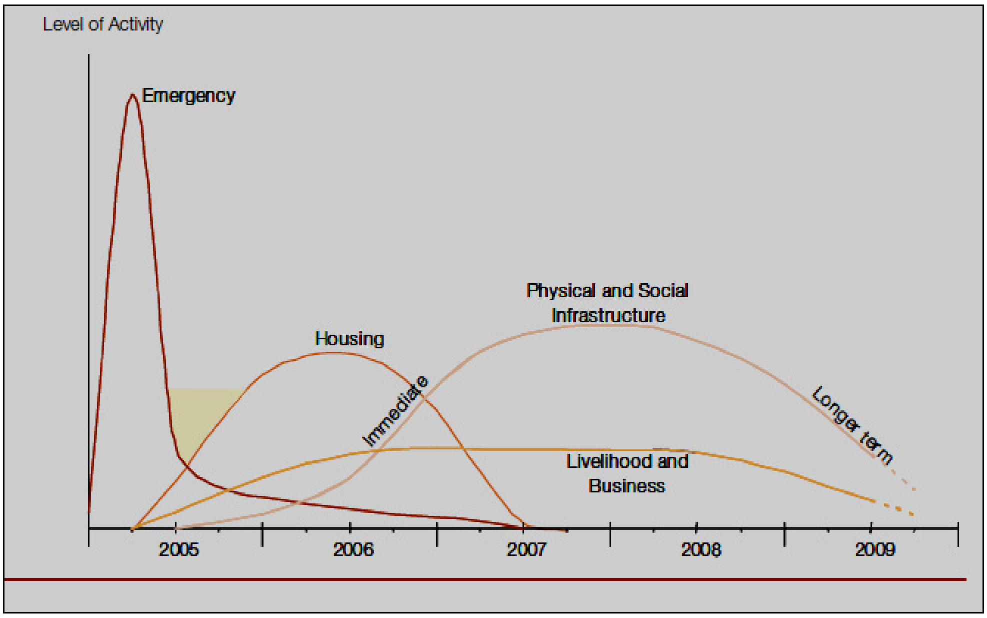



Figure 1.2 Sequencing of emergency and recovery effort (schematic) [Source: BRR and International Partners, 2005]

The various organizations working on reconstructing Aceh have given different approximate numbers of houses needed by tsunami survivors. A monthly report released in February 2008 by the Information centre of Indonesia's Bureau of Rehabilitation and Reconstruction for Aceh and Nias (BRR) indicated the reconstruction progress on the following table.

Table 1.2. Indication of rehabilitation and reconstruction progress (source: Monthly report, Pusdatin BRR, 2008)

| No | Indikator | Dec 2006 | Oct-07 | Nov-07 | Dec-07 | Jan-08 |
|---|---|---|---|---|---|---|
| 1 | Rumah permanen dibangun (unit | 57,000 | 102,063 | 102,063 | 104,287 | 104,287 |
| 2 | Rumah sementara dibangun (unit) | 15,000 | 19,482 | 19,482 | 19,889 | 19,889 |
| 3 | Pengungsi yang masih dibarak (KK)/IDPs still in barrack | 14,317 | 5,287 | 4,149 | 3,698 | 2,229 |

Notes:

1. Built permanent houses
2. Built Temporary houses
3. Tsunami survivor still in barrack

Table 1.2 figures that in 2008 number of permanent houses built were 104.287 whilst 2.229 peoples still live in barracks, which means that there are still many beneficiaries waiting for houses. However, in the years to come, it is likely that the remaining NGO budgets will more and more be used in development work, which aims to eradicate poverty (Dercon et. al., 2007)

## 1.2 Hypotheses

The need to build a large number of houses after the tsunami attack has affected the quality of the house itself. The locally sourced building materials were believed to be depleted due to the over-use (Steinberg, 2007; Chang et. al., 2010; Bapedalda NAD & GTZ-SLGSR, 2006). There are other hypotheses arising regarding these post tsunami houses, such as the resulting indoor comfort, which is to a large degree influenced by the materials used and the house design; and the satisfaction of households with the accommodation is another interesting area of investigation.

## 1.3 Research Problems

Based on the hypotheses and the result of monitoring on post tsunami housing conducted by UN Habitat and Architecture department of Syiah Kuala University (Unsyiah) Indonesia in 2006-2007, there are several houses in some areas of Aceh left unoccupied. Consequently these following questions occur:

- Why do some tsunami survivors not respect the houses donated to them?
- Why do some tsunami survivors leave those houses unoccupied?
- To what extent do the following problems influence the above?
    - Lack of Internal comfort
    - Thermal comfort through building envelope
    - High temperature inside
    - Lack of internal air movement
    - High or low humidity inside
    - Position of houses' openings toward the sun orientation
    - Material used
    - Day lighting provision inside
    - Water supply
    - Electric supply
    - Sanitary problem

- Environmental problem (i.e. lack of trees, dull environment, etc)

As houses are the major needs of people living in post catastrophe affected areas, large numbers of houses are built at the same time, leading to environmental problems (e.g. construction waste, unmanaged use of construction materials provided by nature, e.g. Wood, water, sand etc). These questions become the problems of the research.

## 1.4 Objectives of Research

Based on all research questions above, this study will cover the following objectives:

- To assess the conditions in houses built for Tsunami victims with respect to sustainability issues. This issue is considered important as the post-tsunami houses are of a permanently nature and are expected to be occupied for a long time, not just for a few weeks or months. Therefore the study should investigate the post-tsunami house performance with regard to house designs such as house materials and house construction; thermal comfort; lighting provisions; acoustic performance; health considerations; surrounding environment; waste treatment and general energy performance .
- To investigate and assess the annual indoor thermal environmental performance of some representatives of post tsunami houses. Since the tropics suffer the largest amount of solar radiation, high inside air temperature is the commonest problem in such houses. Currently there are many householders using air conditioners to improve thermal comfort, with the consequent increase in energy use, rather than relying on appropriate climate-sensitive house design. This study also aims to assess the annual inside thermal performance of Acehnese traditional house.
- To provide some building recommendations for good house design for the tsunami disaster victims which consider the local climate.
- To propose alternative house designs applying the building design guidelines recommended in this study responding to thermal building design in the tropics.

## 1.5 Originality of the Research

This research will be most concerned with assessing the environmental quality of post tsunami houses. For European climates, there is much published research dealing with environmental assessment either in general buildings or houses, and most of them are concerned with energy use and thermal comfort (Rijal et. al., 2007; Taylor et. al., 2008;

Hacker et. al., 2008). However, in the case of post tsunami housing in Aceh-Indonesia, so far, no such published works or research has been conducted. The only common topic discussed in any papers in the post tsunami period concerns the report of each NGO in building construction, livelihood and any other activities that have been carried out during the post tsunami period. The paper that was locally published by the local university also only assessed the thermal performance of two types of post tsunami houses in one day measurement (Nawawi, 2005). Therefore establishing the indoor thermal comfort in a large number of permanent post-tsunami houses, combined with environmental assessment, will constitute a useful and original piece of work

### 1.6 Scope of Study

This study will only focus on post tsunami houses in Banda Aceh, the northern part of Sumatra Island, Indonesia, since this part is the capital city of Aceh province where all NGOs locate their main office. The scope of the study will be limited to the provision of internal thermal comfort and the external environmental issues which will be discussed from observation.

### 1.7 Research Methodology

This study aims at finding out the prevalence of post tsunami house performance surveyed at one time. To obtain an overall picture as it stands at the time of the study, the cross-sectional study design as part of the quantitative research method is applied in this study (Kumar, 2005). The data will be acquired by a variety of tools including observations, measurements, and social survey through questionnaire, and simulation through software.

This research deals with these following elements: house description; house materials; thermal comfort; day lighting; house design; environmental/ surrounding assessment; and energy assessment, that will be assessed through measurement, by observation and by questionnaire survey. The survey is conducted in order to assess the feelings of the occupants, which may be different from the measurement carried out with instruments or may support them - an opportunity is presented here to review the thermal comfort prediction methods for this climate. The measurements with instruments will cover thermal comfort, day lighting and air quality, using the parameters below:

- Outside and inside air temperature

- Mean radiant temperature
- Air velocity
- Air relative humidity
- $CO_2$ contamination
- Illuminance (indoor and outdoor) related to day lighting

It is very important to use local climate data to work with the parameters above in order to obtain a reliable result. In this study the local climate data is supplied by BMKG (Badan Meteorologi, Klimatologi dan Geofisika) of Banda Aceh. Those two ways of measurement will be carried out simultaneously in each visit of the field survey.

### 1.8 Thesis Structure

The structure of this thesis is divided into ten chapters. Chapter one in this study presents the brief introduction to the overall thesis.

Chapter two reviews the related literatures that become the back ground of this study. Sustainable housing is initially outlined as it covers the issue carried out in thermal and environmental evaluation of post tsunami housing. Further thermal comfort is reviewed followed by ventilation and indoor air quality; house design including site planning, orientation and building materials; energy efficiency in housing covering household energy use; and environmental issues such as vegetation provision, health considerations in house design and water and waste treatment. After reviewing the sustainability factors of housing in general, the sustainability in post disaster reconstruction is then presented by discussing some samples in post disaster area either applying the approach towards the sustainability or conversely to get failure in adopting it. The final section of this chapter briefly presents the introduction of TAS, the computer- software utilized in this research.

Chapter three outlines the descriptions of Banda Aceh geography and climate as the case study and where the field measurement was carried out. Further, Acehnese traditional and current houses are discussed followed with the post tsunami houses. These houses are reviewed to see their indoor thermal performance as the comparison to the post tsunami housing. Finally the relevant building regulations applicable in Aceh are discussed.

Chapter four presents the field study methodology. The research tools including the overview of questionnaires, experimental data collection and building simulation as part of the predetermined methodology are briefly explained. In this chapter several pictures of data collection are shown to describe how the field work was carried out. To meet the requirement of conducting the survey and research, the ethical issues considerations are also explained which is based on the Heriot-Watt University regulations.

Chapter five discusses the data analysis of post tsunami housings environmental performance based on questionnaire. The analyses go through the house types, house occupancy, house design, house materials, lighting and acoustic performances in the houses. The surrounding performances are analysed from flooding, vegetation provision, water supply, waste treatment, and access to public services. Finally the energy use performances in the houses are simply analysed through the power supply and the monthly average usage of the powers. The overall satisfactory of the householders is also shown as the closing analysis.

Chapter six analyses the indoor thermal performance in post tsunami housing based on field measurements. Indoor thermal performance in the post tsunami housing was assessed through the comparison between the inside and the outside data of air temperature and relative humidity. The inside air movement was also measured in order to understand their relationship. This performance was further compared with the comfort temperatures using the neutral temperature equations applied in the tropics.

Chapter seven discusses the indoor thermal performance simulated with dynamic thermal modelling software TAS. The chapter begins by comparing the predicted indoor air temperature provided by TAS software with the measured data collected during the field trip as the validating process. Further, the annual thermal performance in each house is simulated using the PMV and frequency macros run in MS excel. As the final part of the chapter, the comparison of annual indoor thermal performance of some post tsunami houses and Acehnese traditional house simulated in TAS program is presented.

Chapter eight analyses the influence of house design variables on indoor thermal comfort. The simulations undertaken in this chapter use simple models to which are applied some house design variables to determine the best way to reduce inside air temperature. Based on the simulation using TAS program applying Banda Aceh weather data and supported by relevant literatures, the house design variables are proposed to be applied in the relevant area.

Chapter nine presents the recommendations for house building design in post tsunami areas in a tropical climate. The guidance based on the results of the work in the previous chapters is steps towards environmental-friendly performance and sustainable housing. Following up the indoor thermal comfort assessment, alternative house designs focusing on providing low inside air temperature are also proposed.

Chapter ten is the last chapter presenting the overall research summary. The summary is outlined based on the four research objectives. The recommendation for future research on building sustainable post disaster houses concludes the thesis.

# CHAPTER 2 – LITERATURE REVIEW

## 2.1 Introduction

This chapter reviews the literature as the background of this study. Bringing the concern of the quality of the post tsunami houses within four to five years of the occupancy times, the literature review is focused on sustainable living. Sustainability is very important in influencing the health and good living and therefore surely related to the houses donated for the tsunami victims.

In this chapter the definitions and aspects of sustainable housing is presented. Following that, several factors of that issue becoming the point of assessment and observation are reviewed such as indoor thermal comfort; ventilation and indoor air quality; house design including site planning, orientation and building materials; energy efficiency in housing covering household energy use; and environmental issues such as vegetation provision, health considerations in house design and water and waste treatment. Likewise, the sustainability in post disaster reconstruction is presented by discussing some samples in post disaster area either applying the approach towards the sustainability or conversely to get failure in adopting it. The final section of this chapter briefly presents the introduction of TAS, the computer- software utilized in this research.

## 2.2 Sustainable Housing

The World Commission of Environment and Development (known also as the Brundtland Commission) in 1987 published a report ‘Our Common Future’ which defined sustainable development as ‘Development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (UNCSD, 2007). In building, sustainability is implied in many terms which are currently used, such as sustainable development, green building, green architecture, bioclimatic architecture, eco-architecture, etc. The move towards more sustainable architecture is growing every year.

Development is considered sustainable if it is able to protect the environment (*Bread for the World*, Background Paper No. 129, Washington, DC, March 1993). Related to this, Victor Olgyay (1963) in his book 'Design with climate' wrote about bioclimatic as the term that really supports the idea of protecting the environment. He synthesized bioclimatic with elements of human physiology, climatology and building physics, with a strong advocacy of architectural regionalism and designing in sympathy with the environment.

Another term such as eco-architecture is defined by Roaf (2001) in the introduction of her Ecohouse- Design Guide as a term that sees buildings as part of the larger ecology of the planet and the building as part of a living habitat. This term is actually not a new approach. Long ago people adopted that meaning in their vernacular house design. They experienced their house as part of a living habitat by working with the local climate in providing indoor comfort (Vale, 1991). Vale (1991) explained that what was new in such a definition or in green architecture was the realization that a green approach to the built environment involved a holistic approach to the design of buildings; that all the resources that go into the building be they materials, fuels or the contribution of the users, need to be considered if sustainable architecture is to be produced. All those definitions meet at one point which highlights sustainable building as a building which is designed considering its surroundings, in order to have a mutually beneficial relationship between them.

As Vale (1991) said, this is not a new approach; hence we see in many architectural books the point made that western (developed) countries have become more conscious of environmental issues. Evidence of this is the many green building guides and assessment methods such as BREEAM (Great Britain) – BREAM (2005); GBTool (Canada) – IISBE (2005); LEED (US)-USGBC (2005); EcoProfile (Norway) – Byggforsk (2005) and Environmental Status (Sweden) –Miljo¨ statusfo¨ reningen (2005) (Ali et. al, 2009).

Involving people as occupants in dealing with the housing development process is also part of the sustainability issue in building houses. It will not be widely discussed in this research; nevertheless it is quite a significant issue. There has been some research on this issue (Larasati, 2007; Enginoz, 2005; Barenstein et. al., 2007) that concluded that the lessons learned were as follows: it can accommodate the occupant's preferences regarding house design that mostly follows their habits, culture, and their adaptation to local climate; it can reduce the gap between the levels of society since understanding what occupants need can avoid bias in local housing rules between rich and poor people; and it can educate people how they should treat their house to live well without harming environment.

### 2.3 Thermal comfort in buildings

Thermal comfort is one of the parameters in creating the sustainable living. Thermal comfort in buildings has been widely discussed over the past decades. Human thermal comfort is the main purpose of dealing with thermal comfort in buildings defined by ASHRAE as 'the state of mind that expresses satisfaction with the surrounding environment' (ANSI/ASHRAE Standard 55). CIBSE A (2009) outlines the factors affecting thermal comfort as follows:

- **Air temperature** is 'a physical property of matter that quantitatively expresses the common notions of hot and cold'.It is the most important factor affecting thermal comfort (CIBSE A, 2009).
- **Mean radiant temperature** is 'The uniform surface temperature of a radiantly black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space' (CIBSE A, 2009).
- **Relative air speed** is 'the net mean air speed across the body. For sedentary occupancy the relative air speed is taken as the room air movement only. While for people in motion it will take account of the speed of their movement in addition to the mean room air speed (CIBSE A, 2009).
- **Humidity is** the amount of water vapor in the air. Humidity has little effect on feelings of warmth unless the skin is damp with sweat. High room humidity may occur through a combination of evaporation from moisture sources and poor ventilation, and/or high outdoor humidity, the influence of humidity on warmth in moderate thermal environments may be ignored and humidity in the range 40–70 % RH is generally acceptable (CIBSE A, 2009).
- **Metabolic heat production** is largely dependent on activity (met). The unit used to express the physical activity of humans is the met, where 1 met = 58.2 $W \cdot m^{-2}$ (CIBSE A, 2009).
- **Clothing** is the unit for thermal insulation of clothing, where 1 clo = 0.155 $m^2 \cdot K \cdot W^{-1}$. A clothing ensemble that approximates to 1 clo consists of

underwear, blouse/shirt, slacks/trousers, jacket, socks and shoes (CIBSE A, 2009).

As it is an important element in maintaining the building user satisfaction, thermal comfort standards are required to help building designers to provide an indoor climate that building occupants will find thermally comfortable (Nicol et. al., 2002). It includes ISO7730 and ASHRAE standard 55. Those initial standards are based on the hypothesis that regardless of race, age and sex, human beings are thought to feel comfortable in a narrow, well-defined range of thermal conditions (Ogbonna et. al., 2008; Nicol et. al., 2002). Much of this original work, carried out by Fanger (1972) and others, is based on the testing of subjects in special test rooms, rather than on observations of people working in buildings, and this approach has been questioned in recent years (Nicol et. al., 2002). This inflexibility may result in unnecessary energy use to provide a thermal comfort range which is too narrow.

Table 2.1.Neutral temperatures proposed by previous study

| Writer | Year | Country/ town | Nation | Number of respondents | Neutral temperature ($^0$C) |
|---|---|---|---|---|---|
| Ballantyne | 1967 | Port Moresby | Papua | 34 | 25.6 Ta |
| Busch | 1988 | Bangkok, Thailand | Thai | 1100 | 28.5 ET |
| De Dear | 1990 | Singapore | Singapore | 583 | 28.5 To |
| Karyono | 1993 | Jakarta, Indonesia | Indonesia | 596 | 26.4 Ta (23.9-29.7)<br>26.7 To<br>25.3 Te |
| Feriady (all seasons) | 2001 | Yogyakarta, Indonesia | Indonesia | 525 | 28.75$T_n$ (ASHRAE)<br>27.64$^0$C $T_n$ (Bedford) |

Most of the research done so far has concerned European and North American climates, but some studies have been conducted by Karyono (2000) and Feriady (2004) in determining the neutral temperature in Indonesia. Karyono carried out his study in a multi-storey office building in Jakarta, while Feriadi used naturally ventilated housing in Yogyakarta. Some other thermal studies were also conducted in South-east Asia by Ballantyne, Busch and de Dear (Karyono, 1996), and the results are shown in Table 2.1.

The adaptive thermal comfort which has been widely used by many researchers in determining the actual comfort vote of building occupants was based on the findings of surveys of thermal comfort conducted in the field (Nicol et. al., 2002). This thermal response of subjects is usually measured by asking them for a comfort vote on a descriptive scale such as the ASHRAE or Bedford scale (table 2.2).

Table 2.2.Descriptors for the ASHRAE and Bedford scales

| **ASHRAE descriptor** | **Numerical equivalent** | **Bedford descriptor** |
|---|---|---|
| Hot | 3 | Much too hot |
| Warm | 2 | Too hot |
| Slightly warm | 1 | Comfortably warm |
| Neutral | 0 | Comfortable |
| Slightly cool | -1 | Comfortably cool |
| Cool | -2 | Too cool |
| Cold | -3 | Much too cold |

The fundamental assumption of the adaptive approach is expressed by the adaptive principle: '*if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort'* (Nicol et. al., 2002). This suggests that the comfort temperature is a result of the interaction between the subjects and the building or other environment they are occupying. 'The option for people to react will reflect their situation: those with more opportunities to adapt themselves to the environment or the environment to their own requirements will be less likely to suffer discomfort' (Bedford, 1936).

A number of equations of comfort temperature have been developed by researchers, e.g Humphreys and Auliciems (Feriady, 2004; Singh et. al., 2010); and Nicols (Bouden, 2004) based on field studies in free-running buildings and in warm climates.
Feriady (2004) outlines the brief *Humphrey's* and *Auliciem's* model such as the following:

- *Humphrey's model*:

*Humphreys used the available data of more than 30 comfort surveys from around the world to propose a series of simple correlations of TC prediction. For free-running* *buildings, the comfort temperature (Tco) can be estimated from the mean monthly outdoor temperature (Tm) in ◦C, through the following equation:*

*Tco = 0.53Tm + 11.9 (r = 0.97)........................................................................... (1)*

*The prediction claims to have a standard error of 1 ◦C and applies to temperature range of 10 ◦C < Tm < 34 ◦C.*

- *Auliciem's model:*

*By reanalysing Humphrey's data, Auliciems removed some incompatible information, including the results of more recent field studies, and combined data for buildings with both active and passive climate control. The absence of thermal discomfort is predicted by a simple equation in terms of mean indoor (Ti) and outdoor monthly temperature (Tm):*

*Tco = 0.48Ti + 0.14Tm + 9.22 (r = 0.95)…………………………………………………(2)*

While Bouden (2004) outlines the Nicol's model as follows:

- *Nicol's model:*

*Based on Nicol's first survey in different climatic conditions in Pakistan, he proposed a relation between the neutral temperature and outdoor temperature through the following equation:*

*Tc = 0.38* $T_o$ *+ 17.0…………………………………………………………………………(3)*

*Based on Nicol's second survey in Pakistan, Nicol developed the second regression given by this following equation:*

*Tc = 0.36* $T_o$ *+ 18.5…………………………………………………………………………(4)*

The outside temperature taken in those equations is the average of the monthly mean of the outdoor temperature from published world tables of meteorological data (Humphreys, 1978). Yet the tabulated monthly mean is unsatisfactory because the value of the monthly mean is open to misinterpretation that can be very variable within a month, resulting in changes in the neutral temperature through clothing changes, use of fans etc (Nicol et. al., 2010).

Based on the paper of Nicol et. al. (2010), to estimate the neutral temperature from a fairly small sample of comfort votes on a particular day in buildings, and to avoid the error in the predictor variable, there is the suggested equation in finding the neutral temperature using the Griffiths constants of 0.4 and 0.5 shown as follows:

Table 2.3 Equations for neutral temperature using different values of the Griffiths constant (G) and the running mean constant (a).

| $\alpha$ | $G$ | | | |
|---|---|---|---|---|
| | 0.50 | | 0.40 | |
| | Equation | $R^2$ | Equation | $R^2$ |
| 0.45 | $0.334T_{rm} + 18.9$ | 0.354 | $0.304T_{rm} + 19.1$ | 0.258 |
| 0.80 | $0.331T_{rm} + 18.8$ | 0.358 | $0.314T_{rm} + 18.9$ | 0.263 |
| 0.96 | $0.317T_{rm} + 19.0$ | 0.310 | $0.304T_{rm} + 19.1$ | 0.224 |

……………………(5)

Source: Nicol et. al. (2010)

$T_{rm}$ is the exponentially weighted running mean temperature for any day which is expressed in the series:

$$T_{rm}= (1-\alpha) \{T_{od-1}+ \alpha\, T_{od-2}+ \alpha^2\, T_{od-3......}\} \quad \text{………………………………………………(6)}$$

Where α is a constant (<1) which gives 'half life' values of about a day (0.45), half a week (0.8) and 2–3 weeks (0.96);while ($T_{od-1}$) etc. are the 24-h daily mean temperatures for yesterday, the day before and so on. The value of $T_{rm}$ for any day is then simply calculated by this formula*:*

$$T_{rm}= (1-\alpha)T_{od-1}+ \alpha\, T_{rm\,-1} \quad \text{………………………………………………………………(7)}$$

This running mean is useful to describe changes in clothing in response to changing temperatures (Humphreys, 1979)

## 2.4 Ventilation and Indoor Air Quality

Apart from considering indoor thermal comfort, ventilation and indoor air quality also play an important role in approaching the sustainability. Randall McMullan (2002) defined Ventilation in his book 'Environmental Science in Building' as the process of changing the air in a room or in some other internal space processed continuously with new air taken from a clean source. Since 1990, BRE has underlined that adequate fresh air ventilation within a building is vital for health. Once it is reduced below a certain threshold, pollutants are inadequately removed and humidity levels rise alarmingly (Crowther, 1996).

In another issue such as sick building syndrome, ventilation is an urgent need that must be provided naturally or mechanically if the building situation does not allow natural ventilation. There is a significant relationship between SBS symptoms and ventilation rate. Based on the study 'Quantitative relationship of sick building syndrome symptoms with ventilation rates' (Fisk et. al., 2009), as the ventilation rate drops from 10 to 5 l/s-person, relative SBS symptom prevalence increases approximately 23% (12% to 32%), and as ventilation rate increases from 10 to 25 l/s-person, relative prevalence decreases approximately 29% (15% to 42%). In another study which focused on school conditions, poor indoor environmental quality (IEQ) which is caused by poor ventilation has been related to reduced performance and attendance of students (Mendell and Heath, 2005). This is also possible in houses and can reduce family harmony.

## 2.5 House design including site planning, orientation and building materials

House design taking into consideration site selection will achieve many benefits (Chiras, 2004; Wines, 2000). In an area where the sun is mostly to the south, orienting a house to the south reduces the annual heating bill by 10 percent, shifting a few of the windows to the south side increases the solar gain and can decrease heating bills by up to 30 percent, and there are further benefits by orienting the house in the optimum direction relative to the sun. Several factors contribute to a site with optimal green features; choose a site with good solar access; choose a sloping site for earth sheltering; seek favourable microclimate; select a dry, well-drained site; select a site with stable subsoils; avoid natural hazards; avoid marshy areas; select a site suitable for growing food; select a site that offers building resources; minimize bulldozing for roads and driveways; avoid noise and pollution; balance view with vital needs and do not destroy beauty in your search for it (Chiras, 2004).

Chiras, (2004) also mentioned that building materials must also be considered in sustainable housing, according to the following criteria: produced by socially and environmentally responsible companies; produced sustainably-harvested, extracted, processed, and transported efficiently and cleanly; low embodied energy, locally produced, made from recycled waste, made from recycled or renewable materials; durable; recyclable; nontoxic; efficient in their use of resources; reliant on renewable resources; and non-polluting.

## 2.6 Energy efficiency in housing, covering household energy use

As has been explained in the introduction to chapter 2, buildings are responsible for a large amount of the total world annual energy consumption (Omer, 2007; Roaf, 2001) hence once it is well managed to reduce the energy use, it will help to save the environment from damage. Omer (2007) wrote that one way of reducing building energy consumption is to design buildings which are more economical in their use of energy for heating, lighting, cooling, ventilation and hot water supply.

Still in his journal, Omer (2007) wrote that energy-based living standards in developing countries are clearly below the standards in developed countries, caused by low level of access to affordable and environmentally sound energy. However in recent years, many programmes for such achievement have been promoted either by government or Non Governmental Organizations (NGOs) to make people more familiar with energy conservation.

## 2.7 Environmental issues such as vegetation provision, health considerations in house design; water and waste treatment

a. Health consideration

Health considerations in buildings are an important aspect of the environmental issues. The influence on human wellbeing and health may be considered as physical, chemical and biological (Singh and Walker, 1996) which can cause what is commonly known as Sick Building Syndrome (SBS) such as sensory irritation of the eyes, nose, throat; neurotoxic or general health problems; skin irritation; nonspecific hypersensitivity reactions; and odour and taste sensations (Godish et. al., 2001). SBS can be caused by these following problems (Melius, 1984 cited in LHC, 1990):

- Inside contamination: toxic agents from electrical equipment such as air conditioner, fridge, gas cooker etc.
- Contamination (outside): chemical or other toxic substances originating from a source outside the building, e.g. motor vehicle exhaust fumes, construction activity.
- Contamination (building fabric): the material used to construct the building (figure excludes asbestos), e.g. formaldehyde, fibreglass
- Inadequate ventilation: due to low levels of multiple contaminants and/or poor ventilation

- Hypersensitivity pneumonitis: due to a reaction to micro-organisms in the building environment
- Cigarette smoking inside the house worsened with lack of ventilation in the houses. Cigarette smoking is a very urgently health issue in Aceh, since the men mostly ignore the bad effect of it. There are also no strict regulations of 'no smoking inside the buildings' making people to neglect it.
- Problems caused by humidity, noise, illumination and scabies

b. Vegetation provision

Vegetation provision is also aimed at creating a good environment. Vegetation can reduce the summer cooling loads in residential buildings (Masmoudi et. al., 2004; Sari, 2005) and some of this work includes the use of green roofs in providing good thermal comfort. Local vegetation is more likely to be adapted to the local climate, which means it has the best possibility for reducing the cooling load by considering its characteristics such as leaf surface, height etc.

c. Water supply

Water supply is regarded to be sustainable if it continues to be available for the future period with the same quantity and at the same quality (The water page, 2011). To achieve the sustainable water supply, the following water sources should be considered (Southwest Florida Water Management District, 2001):

- *Conserved water*
- *Reclaimed water: water that has received at least secondary treatment and is reused after flowing out of a wastewater treatment facility*
- *Stored water: the withdrawal of water from a river or other surface water source during rainy season, when water is more plentiful. The water can be stored for later use.*
- *Desalination: a process that removes salt from seawater or from brackish (slightly salty) water to produce fresh, drinking–quality water*
- *Land acquisition*

Safe drinking water should consider microbial and chemical quality, since these two contaminations are associated with health risks. With regard to this matter, there should be adequate legislation standards and codes to support the effective control of drinking-water quality. The precise nature of the legislation in each country will depend on national, constitutional and other considerations. (WHO, 2008)

d. Waste treatment

Waste treatment is obviously related to sanitation. Sanitation is labelled with sustainable piece if it concerns with health including any aspects of hygiene and nutrition; environment and natural resources; technology and operation as the tool to function and ease the systems; financial and economic issues dealing with the maintenance and operation cost; and socio-cultural and institutional aspects as the criteria to get the sanitation accepted by the local people (Water Aid, 2008). These criteria must be met in applying any type of sanitation systems.

In emergency case such as in post disaster area, where the disaster has just stopped and peoples are just displaced and sheltered in temporary dwellings, the short term provision of excreta disposal facilities are highly needed to built. Defecation field is the only immediate solution to excreta containment. Meanwhile for the medium terms are such as communal latrines and shallow latrines or families (Davis et. al., 1995). These two terms need the above considerations to approach the sustainable sanitations. The location should be considered as well to avoid the pollution.

The long term of sanitation systems must be provided in post disaster area where post disaster shelters are shifted from temporary dwellings to permanent houses. Simple pit latrines and ventilated improved pit latrines are the simple systems than can be provided for the longer term (Davis et. al., 1995). More sophisticated systems using septic tank can also be installed. For the large community, biogas plant (anaerobic reactor) for pre-treatment followed by a post-treatment stage using a French drain system (anaerobic filter) and a vegetated garden can be applied. This system was carried out in canteen area in one of places in Banda Aceh as one the tsunami affected areas (Kumar, 2008). Yet, there is clearly no single 'sustainable' model for all situations: a particular sanitation solution might fulfil the criteria to a great extent in one setting, but might be completely unsustainable in another (WaterAid and IWC, 2008).

### 2.8 Sustainability in Post-Disaster Reconstruction

After developing a brief understanding of factors that should be considered in the sustainability of housing, this section will go further to develop an understanding of employing sustainability in post-disaster reconstruction. UNDP defines sustainable reconstruction as a holistic approach where environmental, social, technical, economic and institutional concerns are considered in every step and activity of reconstruction (UNEP, 2007). An initial work which is urgently needed to go through post-disaster resilience is providing shelters. The main features of sustainable shelters recommended by UNEP are (UNEP, 2007):

- Made with simple, low cost, robust and practical techniques
- Resistant to natural hazards
- Environmentally sustainable and energy efficient
- Socially, aesthetically and culturally appropriate to the context
- Made with locally available building materials, tools and skills
- Flexible for future upgrading and extensions
- Easy to maintain
- Easy to disconnect, reuse and recycle in its parts

In another word, Lisa (2010) categorises this approach as green rehabilitation which aims at reducing the impact of the built environment on human health and natural habitat. It encourages more respectful use of prime sources (land, water, air, green cover and energy), an emphasis on renewable sources, energy efficient building practices and the minimization of waste. Even though all stakeholders dealing with post-disaster resilience are familiar with it, this approach has nevertheless not been widely adopted. There are several case studies which fail to apply this approach.

Dimen (2008) describes the failure of a post-disaster reconstruction project conducted in the villages of Dinar, Turkey following the 1995 earthquake. The physical, socio-cultural and economic factors were not considered during the decision making process of the project. In the aftermath, 13 years after the occupancy time, observation shows that there are negative aspects from the point of view of sustainability. The users had to make additions to the houses and construct new buildings on the lots. In addition, some of the users had to repair parts of their houses because of problems with the buildings due to workmanship.

Karyono (2010) through his field measurement found that the new Ngelepen dome housing in Sengir Hamlet, Yogyakarta, Indonesia built for the victims of the earthquake on May 27th 2006 failed to provide internal comfort. The dome concrete house which is very unsuitable for the Indonesian tropical climate has created an inside air temperature 2.2$^0$C higher than the outside air temperature. The dome form was merely designed for resistance to the earthquake. The awareness of the hot, humid Indonesian climate which needs large overhang to shade the buildings was negligible. This strange form of house that does not transform the habitual activities of local people forces people to accommodate more rooms directly connected to the open air, such as kitchens, etc. Later some overhangs above the apertures such as doors and windows were also added by the householders either to protect them from direct solar radiation or the rain sprays (Pandelaki et. al., 2008).

Boen et. al. (2005) through the study of 'Cultural Considerations for Post Disaster Reconstruction' found that local culture should be well considered to ensure the sustainability of interventions undertaken as part of post-disaster reconstruction. Two case studies prove this consideration. The first case study happened in Indonesia where the government relocated the victims attacked by the earthquake on 12 December 1992 from their original location (Wuring village and a village in Babi island), now regarded as dangerous, to a new location (Nangahure and Nangahale respectively). However, eight years after the 1992 earthquake, many houses in Nangahure and Nangahale were abandoned because people moved back to their original village.

The second case happened in the Marathwada region of Western India. The same thing happened that the relocated victims of the 1993 Earthquake moved back to their original village. These case studies show how the new atmospheres provided in the new places which totally different from their original places. The differences included the house forms, available livelihoods, and neighbourhoods with different religion and character. The differences make the relocated people feel away from home in their environment, and so they choose to vacate their new places. After returning to their original place, they rebuilt the restricted location in same conditions as the one before the disaster, meaning that there were no considerations of earthquake resistance applied to their houses. This meant all the effort of the Government and various NGOs towards 'information dissemination' and 'technology transfer' was wasted.

Some other similar cases in different countries [Vladimir Ladinski (1995); Robert Geipel (1991); Miculax and Schramm (1989); Richard Hughes (1987); and Sultan Barahkat (1993)] also provide clear evidence that lack of cultural continuity and compatibility is certainly a key issue resulting in increasing disaster vulnerability after post-disaster reconstruction (Boen, 2005). Nevertheless, relocation does not mean to be unsustainable if it is applied with very careful planning, thorough analysis and the integration of social functions as part of social life.

Lisa (2010) figures a model in the process of applying the sustainability in post disaster reconstruction which was carried out in Aurlaha, India. As a remedy to the victims of the 2008 Kosi flood, the Government of Bihar with national organizations and institutions achieved a rapid and sustainable reconstruction. The actions based on 'Owner Driven Rehabilitation' (ODR) are aimed at being eco-friendly, climate sensitive and environmentally-friendly solutions and adopting local techniques in place of factory-made materials. The approaches used in the reconstruction process are as follows:

- House design:

The process was started by assessing the damage, local resources and practices. Further, a community meeting was arranged to identify people's housing needs and expectations and to introduce the principles of the ODR. The house design recommended by the donor was built of bamboo since it was acknowledged to be the most widely available and rapidly renewable resource in the area. The Indian National Bamboo Commission states that up to 80% of bamboo growing in India comes from these areas. This fact makes an obvious conclusion that the local population has lived in houses made of bamboo (together with other materials like timber, earth and thatch) for thousands of years.

- Use of renewable energy:

*Lighting*: Solar lighting was utilised. A Photo Voltaic panel was exposed south-facing and connected to a battery charger. LED lights were employed to allow greater energy-efficiency of the system and durability.

*Cooking*: Biomass was the only fuel employed for fire cooking. However, since this fuel pollutes the air, hence biogas was proposed, yet still under experimentation. It was successful to be applied in Abhiyan's project in Gujarat

*Water use and conservation*: Each household was provided with one manual water pump. However, the groundwater was contaminated with high concentrations of salts and arsenic. The most suitable drinking water might be provided through rainwater harvesting followed by its distillation or purification.

*Sanitation issues*: One permanent eco-san facility was installed in each house. It consisted of a dry compost pit latrine, where the separation of human waste in different containers allowed their reuse for manure and irrigation of plants.

*Waste management*: any of the waste produced was re-employed as fodder, fuel for fire cooking or natural fertilizer.

## 2.9 TAS- the Computer- Software Utilized in this Research

With regard to indoor thermal assessment in the post tsunami housing, TAS will be used to carry out the task. TAS is a software tool which simulates the thermal performance of buildings. The main applications of the program are in assessment of environmental performance, prediction of energy consumption, plant sizing, analysis of energy conservation options and energy targeting. The fundamental approach adopted by TAS is dynamic simulation. This technique traces the thermal state of the building through a series of hourly snapshots, providing the user with a detailed picture of the way the building will perform, not only under extreme design conditions, but throughout a typical year. This approach allows the influences of the numerous thermal processes occurring in the building, their timing, location and interaction, to be properly accounted for (TAS EDSL theory, 2011).

### 2.9.1 The calculation principles utilised in TAS simulation

The following overview is adapted from TAS Theory Reference Manual. It outlines the main environmental parameters considered and applied by the TAS software during the simulation process. TAS simulates the thermal state of the building by accumulating of variety of heat transfer mechanisms as shown in figure 2.1.

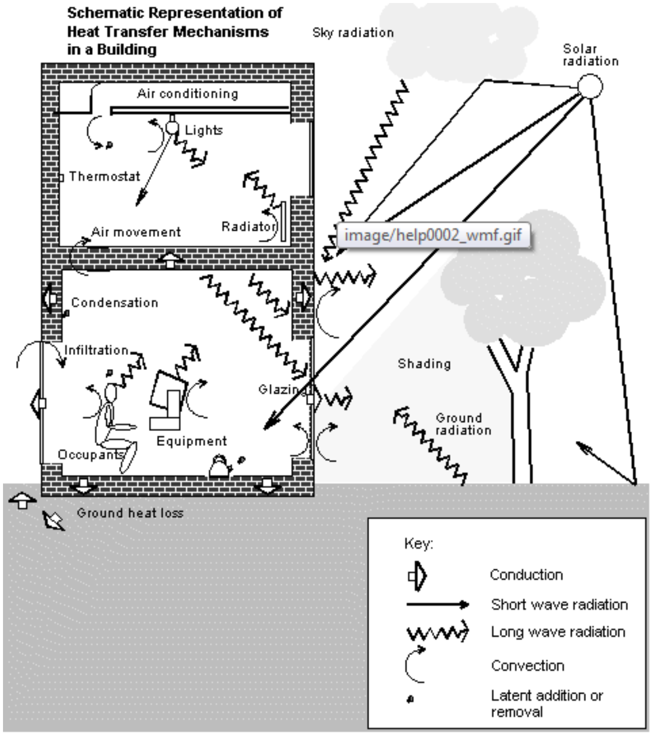



Figure 2.1 Schematic representation of heat transfer mechanism in a building (TAS EDSL theory, 2011).

a) **Conduction**

Conduction in the fabric of the building is treated dynamically using a method derived from the ASHRAE response factor technique. This efficient computational procedure calculates conductive heat flows at the surfaces of walls and other building elements as functions of the temperature histories at those surfaces. The equation utilised by TAS to calculate the conduction heat flux between two surfaces are outlined as follows:

Internal surface conduction heat flux ($W^{cond,\ int}$):

$$W^{cond,int} = X^0 T^{int} + X^1 \left\langle T^{int} \right\rangle - Y^o T^{ext} - Y^1 \left\langle T^{ext} \right\rangle + \sum_{n=1}^{N} V_n^{int} v_n$$

External surface conduction heat flux ($W^{cond,\ ext}$):

$$W^{cond,ext} = Z^0 T^{ext} + Z^1 \left\langle T^{ext} \right\rangle - Y^o T^{int} - Y^1 \left\langle T^{int} \right\rangle + \sum_{n=1}^{N} V_n^{ext} v_n$$

Where:

$W^{cond,\ int}$: the internal surface conduction heat flux (W/m$^2$)

$W^{cond,\ ext}$: the external surface conduction heat flux (W/m$^2$)

$T^{int}$ : the temperature on the internal surfaces ($^0C$)

$T^{ext}$ : the temperature on the external surfaces ($^0C$)

X : the previous time step

$X^0$, $X^1$, $Y^0$, $Y^1$, $Z^0$, $Z^1$ : the response factors ($W/m^2K$) which characterize the wall's response to recent surface temperature history

$V_n$( n= 1,2,....N) : are set of normal co-ordinate variables (with the dimensions of heat flux ($W/m^2$) which describe the thermal state of the wall at time-step in relation to a set of functions which is updated at each time step using the previous time step's surface temperature

$V^{int}_{n,}$ $V^{ext}_{n}$ ( n= 1,2,....N): are dimensionless constants which characterise the relationship between the surface fluxes and the normal co-ordinate variables

The conduction heat flows into the surfaces of the building components are calculated by multiplying the surface fluxes by the component area, A, which is the mean of the internal and external surface areas provided by 3D-Tas.

$q^{cond,int} = A\ W^{cond,\ int} = A\ X^0T^{int}\text{-}AY^0T^{ext}+ q^{hist\_cond\ ,\ int}$

and

$q^{cond,int} = A\ W^{cond,\ int} = A\ Z^0T^{ext}\text{-}AY^0T^{int}+ q^{hist\_cond\ ,\ ext}$, where:

$q^{hist\_cond\ ,\ int}$ and $q^{hist\_cond\ ,\ ext}$ : the sum of all the historical terms which are related to the results from previous time-steps

b) **Convection**

Convection at building surfaces is treated using a combination of empirical and theoretical relationships relating convective heat flow to temperature difference, surface orientation, and, in the case of external convection, wind speed. The convection coefficient at external building surfaces is calculated from hourly values of the wind speed

a) External convection:

The external convective heat flow, $q^{conv,\ ext}$ (Watts), is calculated by multiplying $W^{conv,ext}$ by the effective component surface area, A (the mean of the internal and external surface areas provided by 3D-Tas):

$q^{conv, ext}=AW^{conv,ext}=Ah^{ext}(T^0air-T^{ext})= A(5.8+4.1v_m) (T^0air-T^{ext})$

Where:

$H^{ext}$: the external convection coefficient (W/m$^2$)

$T^0$ : the outside air temperature;

$T^{ext}$ : is the external surface temperature.

$v_{m:}$ the wind speed measured at the meteorological station at a height of 10m

- Internal convection

The internal convective heat flow, $q^{conv,\ int}$ (Watts), from the air to the surface is calculated by multiplying $W^{conv,int}$ by the effective component surface area, A:

$q^{conv, int} = AW^{conv,int} = Ah^{int}(T^{air}-T^{int})$

where:

$h^{int}$ = the convective heat transfer coefficient (W/m$^2$K) applying between a surface and room air.

$h^{int}$ for window which is set out by Alamdari and Hammond (1984):

$$h^{int} = \left[\left\{a\left(\frac{\Delta T}{L}\right)^{1/4}\right\}^6 + \left\{b(\Delta T)^{1/3}\right\}^6\right]^{1/6}$$

| | a | b |
|---|---|---|
| Vertical surface (horizontal heat flow) | 1.50 | 1.23 |
| Horizontal surface upward heat flow | 1.40 | 1.63 |

$h^{int}$ for vertical wall: $h^{int} = h^H+1.23(\Delta T)^{1/3}$

$h^{int}$ for horizontal wall: $h^{int} = 1.63(\Delta T)^{1/3}$

$h^{int}$ for horizontal surfaces when the heat flow is downward (Alamdari and Hammond):

$h^{in\,t} = 0.6[(\Delta T/L^2]^{1/5}$

$h^{int}$ for slooping wall, upward heat flow: $h^{int} = h^{up} + (h^{hor} - h^{up})(\sin\gamma)^{1/4}$

$h^{int}$ for slooping wall, downward heat flow: $h^{int} = h^{down} + (h^{hor} - h^{down})(\sin\gamma)^{1/4}$

$\Delta T$: the absolute temperature difference (K) between the room air (temperature $T^{air}$) and the surface (temperature $T^{int}$);

$\gamma$ : the angle between the inward-facing surface normal and the vertical

**c) Infiltration**

Infiltration is used in TAS to describe the user-specified exchange of air between a building zone and the exterior by natural ventilation. Infiltration carries both sensible and latent heat into or out of the zone.

$Q^{inf} = m^{inf} c_p (T_o^{air} - T^{air}) = [(\rho^{air} aV)/3600]\, c_p (T_o^{air} - T^{air})$, where:

$Q^{inf}$: the sensible heat gain due to infiltration

$m^{inf}$: the infiltration air mass flow rate (kg/s),

$c_p$: the specific heat capacity of air at constant pressure, for which the value 1012 J/kgK is taken (corresponding to a humidity ratio of about 0.003 kg/kg);

$T_o^{air}$: the outside air temperature

$\rho^{air}$: 1.210 Kg/m$^3$(the density of air at standard atmospheric pressure and a temperature of 20C):

a: the air change rate (air changes per hour),

V: the volume of air in the zone

**d) Air movement**

Air moving between zones in a building carries with sensible heat and water vapour, and thus affects the thermal balance in the zones concerned. Air Movement may represent either natural or mechanical ventilation. The total sensible heat gain, $Q^{am}$ (Watts), into zone z due to air movement is given by:

$$Q^{am} = \sum_{s=0}^{Z} m_{sz} c_p (T_s^{air} - T^{air}) \quad (5-6)$$

where:

Z: the number of zones in the model

$M_{sz}$: the mass flow rate from source zone s (with zone 0 representing the outside air) to zone z

$T_s^{\ air}$: the air temperature in source zone s (or the outside temperature in the case);

e) **Long-wave radiation exchange**

Long-wave radiation exchange is modelled using the Stefan-Boltzmann law, using surface emissivities from the materials database. Long-wave radiation from the sky and the ground is treated using empirical relationships

The external radiation gain on the building surface from sky and ground is modelled as: $q^{rad,\, ext} = e^{ext}\, AR^{env} - AR^{ext}$, where:

$R^{env}$: the total long-wave flux incident on an external building

$R^{ext}$: a long-wave radiant flux by the surface = $R^{ref} + h^{rad,ext} T^{ext}$

$R^{ref} = 273.15h^{rad,ext} - 3\, \varepsilon^{ext}\, (\Theta^{ext}{}_{(ref)})^4$

$h^{rad,ext} = 4\, \varepsilon^{\, ext} (\Theta^{ext}{}_{(ref)})^3$

$\varepsilon^{\, ext}$: the emissivity of the surface

$\Theta^{ext}$: the absolute temperature of the surface

A: the component area (the mean of the internal and external surface areas provided by 3-D TAS)

$T^{ext}$: the external surface temperature

### 2.9.2 Validation for the thermal simulation model

Mitsimpona (2007; citing Bloomfield et. al., 1992; and Tang, 2002) outlined in her study that the validation of building thermal performance simulated in TAS can be obtained from the following ways:

- **Validation with onsite measurement**: this is the most accurate way to validate a thermal simulation. It is carried out by comparing the results with onsite measurement by assuring that the simulation has been carried out using actual occupant activities and weather data. Yet this method faces the difficulty to control the occupants' activities within the building.
- **Validation with existing case comparison**: It is carried out by using the existing results from previous published experiments which is assumed to be accurate.
- **Validation with inter-model comparison:** It aims at obtaining a robust simulation model as a control parameter. First the robust model must be accurate by being validated with existing results. It is then adjusted to the parameters of the building simulated in the study.

### 2.9.3 Justification of TAS

TAS software was selected to assess the thermal performance of post tsunami housing in this study for the following reasons:

a. Robust and accurate. Crawley et. al. (2005) in the joint report of 'Contrasting the Capabilities of Building Energy Performance Simulation Programs' mentioned that TAS has 20 years commercial use in the UK and around the world. It has the reputation of robustness, accuracy and a comprehensive range of capabilities. The accuracy is also agreed by Alamdari et.al (1984, cited in Abdullah, 2007). This software is also regarded as powerful design tool in optimising the building's environmental, energy and comfort performance (Jones, AM cited in Abdullah, 2007).
b. TAS has been used widely in building research. Some previous researchers utilised TAS building simulation software in their research as follows:

- Abdullah (2007, 2009), utilised TAS to model thermal stratification within multi-level atrium in three-storey atrium in southern China.

- Zakaria et. al. (2008) used TAS to generate the thermal and energy performance of roof insulation for residential buildings in tropical climate of Malaysia
- Sagia (2007) applied TAS, the dynamic thermal simulation to gain understanding of the energy behaviour of the double enclosure typology; and to suggest a low-density typology for commercial buildings to be applied in the cultural and climatic context of Athens, Greece, with minimal demand for conventional cooling.
- Musao et. al. (2007), used TAS to investigate the degrees to which energy use in laboratory buildings may be influenced by interior
- Demirbilek et. al. (2008), used TAS to work on the potential of reducing cooling loads through façade and glass types in medium and high-rise office buildings in sub-tropical climatic regions
- Van Moeseke et. al. (2005), used the default pressure coefficients evaluation based on wind tunnel tests for a high rise building provided in TAS to bound knowledge of wind pressures on buildings with natural ventilation potential
- Carbon trust (2005), Used TAS from EDSL to model the Thermal, ventilation and daylight in Great Glen House, Scottish Natural Heritage's new headquarters in Inverness
- Schuss et. al. (2010) used TAS (EDSL 2008) to estimate the night cooling effect and virtually test the new control approach. For this purpose, measurements of air change rates were the starting point for different natural ventilation simulations
- Mitsimpona (2007) utilised TAS to study the thermal behaviour of buildings equipped with double skin facade and the conventional types of facade in the Greek climate.
- Fisher (2008) carried out the wind tunnel testing on the study of natural ventilation in an existing urban building. Due to the complexity of air movement around buildings, the results were also verified by a number of wind tunnel tests.

The various studies using TAS especially the research carrying out the case in tropical Malaysia persuade further reasons to utilise the software in this study which is also located in tropical climate.

c. As previously mentioned, TAS uses dynamic simulation to perform the building thermal performance through a series of hourly snapshots throughout a typical year. These features together with the use of 3D in creating the model make the result easily understood by the readers.

## 2.10 Conclusion

The sustainability in housing is reviewed in this section. Indoor thermal comfort is regarded as a quite significant issue, since it is related to the house design and building materials. Indonesia, as a tropical country which has a hot and humid climate should be concerned with the building material. Since if it is neglected, the indoor thermal performance may be worse. Thermal comfort in this chapter is discussed based on the neutral temperatures found by some researchers in various countries with varied research methodologies. Likewise ventilation and indoor air quality are briefly reviewed. Related to this, Sick building Syndrome (SBS) is also discussed which is partly caused by the poor ventilation and indoor air quality.

Sustainable housing is quite a complex issue that may bring many aspects influencing the occupant's life into concern. The house design, including site planning, orientation and building materials, are reviewed in this section. These aspects do have significant influence on indoor thermal comforts, which are considered in the further chapter dealing with design variables in the tropics. Energy efficiency in housing, covering household energy use is reviewed in very brief notes. This is actually a big issue in the current building sector. However, energy-based living standards in developing countries are clearly below the standards in developed countries which are caused by low levels of access to affordable and environmentally sound energy. Environmental issues such as vegetation provision, and water and waste treatment are also very important. This is discussed together with sanitations applicable in post-disaster areas.

Second to last, sustainability in post-disaster reconstruction is reviewed. This section discusses some case studies dealing with post-disaster reconstruction in some countries. Sustainability should be applied with careful planning, thorough analysis and the integration of social functions as part of social life. House designs must be eco-friendly, climate sensitive and filled with environmentally-friendly solutions while adopting local techniques in place of factory-made materials. The wrong analysis may lead to failure during the post-occupancy time, meaning the waste of a lot of money and effort. The last section reviews TAS building simulation software used in this study. There has been various research conducted using this software which justify its utilization as an accurate tool for building research.

# CHAPTER 3 – INDONESIAN HOUSE AND BUILDING REGULATIONS

## 3.1 Introduction

Banda Aceh was a case area selected to assess the post tsunami housing environmental performance built for the tsunami victims of 26th December 2004. There are several reasons for the choice of Banda Aceh. First, Banda Aceh is the capital city of Aceh province, the region worst affected by the tsunami. Most of the NGOs working in reconstructing Aceh located their main office in this city. Second, the surveyors involved in this study were from the Syiah Kuala University which is also located in Banda Aceh city; therefore taking Banda Aceh was beneficial to reduce survey time and costs. With regard to the conflict affecting Aceh province which ended in 2005, this area of study may also ensure the safety of the surveyors.

This chapter outlines the descriptions of Banda Aceh geography and climate. Further, Acehnese traditional and current houses are described followed with the post tsunami houses. Finally the relevant building regulations applicable in Aceh are discussed.

## 3.2 Location and Climate

### 3.2.1 Indonesia

Indonesia where Aceh is situated lies between latitudes 11°S and 6°N, and longitudes 95°E and 141°E. It consists of 17,508 islands, about 6,000 of which are inhabited with over 238 million people (Wikipedia, 2011). These are scattered over both sides of the equator. The largest islands are Java, Sumatra, Borneo which is also called Kalimantan (shared with Brunei and Malaysia), New Guinea (shared with Papua New Guinea), and Sulawesi. Indonesia shares land borders with Malaysia on Borneo, Papua New Guinea on the island of New Guinea, and East Timor on the island of Timor. Indonesia shares maritime borders across narrow straits with Singapore, Malaysia, and the Philippines to the north, and with Australia to the south. The capital, Jakarta, is on Java and is the nation's largest city, followed by Surabaya, Bandung, Medan, and Semarang (Witton, 2003).


Figure 3.1 Indonesia in the world map.

(Source: http://maps.google.co.uk/maps?ie=UTF-8&hl=en&tab=wl)

The climate of Indonesia is almost entirely tropical. The characteristics are heavy rainfall, high humidity, high temperature, and low winds. It has two seasons namely wet season which is from November to March and dry season that is from April to October. Rainfall in lowland areas averages 180–320 cm (70–125 in) annually, increasing with elevation to an average of 610 cm (240 in) in some mountain areas. In the lowlands of Sumatra and Kalimantan, the rainfall range is 305–370 cm (120–145 in); the amount diminishes southward, closer to the northwest Australian desert. Average humidity is 82%' (Nations Encyclopedia, 2011).

The temperatures on land remain fairly constant due to the uniformly warm waters and the effect of altitude. At sea level, the mean annual temperature is about 25– 27°C, the inland and mountain areas averaging 26 °C, and the higher mountain regions, 23 °C. Temperature varies little from season to season, and Indonesia experiences relatively little change in the length of daylight hours from one season to the next. The difference between the longest day and the shortest day of the year is only forty-eight minutes (weather online, 2011).

### 3.2.2 Banda Aceh


Figure 3.2 Indonesian map (Source: http://maps.google.co.uk/maps)

**Banda Aceh** is the provincial capital and largest city in the province of Aceh, Indonesia, located on the island of Sumatra. The city regency covers an area of 64 square kilometres and according to the 2000 census had a population of 219,070 people (Dedy GNR, 2008, p.7).

Banda Aceh city is located at the north-western tip of Indonesia, at latitude 5.51, longitude 95.41, and the average altitude 8 metres. Based on data for the year 2008 (BMKG, 2008), the average temperature, humidity in Banda Aceh are $27^0$C, 78% respectively. The average precipitation amount in this given year is 100.6mm with the highest average of rain frequency occurring in November, December, January and March. The prevailing wind predominantly blows to south east with average wind speed is 2 m/s. (Sari, 2010).

In this study, the measurement using the weather data was carried out in year 2009. The simulation was also set up to use the weather data in this year. Corresponding with this, the complete weather data of year 2009 was obtained from BMKG (Meteorology office) in Banda Aceh. During this year the slightly warmer months and hence lower relative humidity are April, May, June, July, September, and October. Meanwhile, the air speed and cloud remain almost uniform throughout the year.

The followings are the summary of weather data of year 2009.

Table 3.1 Weather data of Banda Aceh city

| parameter | Mean values | Jan | Feb | March | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature ($^0$C)** | Avg | 25.7 | 26.6 | 26.6 | 27.8 | 27.7 | 28.6 | 28.6 | 27.4 | 27.6 | 27.4 | 26.5 | 26.6 |
| | max | 29.2 | 31.0 | 31.5 | 32.7 | 32.7 | 33.5 | 33.8 | 31.9 | 32.0 | 31.9 | 30.8 | 30.7 |
| | min | 22.7 | 22.4 | 22.6 | 23.7 | 22.7 | 22.6 | 23.9 | 23.7 | 23.6 | 23.6 | 23.7 | 23.7 |
| **Relative Humidity (%)** | Avg | 84.3 | 80.8 | 82.9 | 79.2 | 78.0 | 67.7 | 67.7 | 75.1 | 73.5 | 76.1 | 84.9 | 85.2 |
| | max | 95.5 | 95.7 | 95.6 | 95.9 | 94.6 | 89.4 | 88.9 | 92.7 | 92.6 | 92.9 | 96.8 | 96.8 |
| | min | 67.4 | 59.5 | 61.2 | 56.5 | 53.3 | 46.1 | 45.5 | 54.1 | 52.0 | 51.8 | 64.0 | 66.4 |
| **Air speed (m/s)** | Avg | 2.5 | 1.9 | 2.0 | 1.8 | 1.8 | 2.1 | 1.9 | 1.9 | 1.9 | 1.8 | 2.0 | 2.9 |
| | max | 4.4 | 3.4 | 3.7 | 4.0 | 4.0 | 4.3 | 4.3 | 4.2 | 4.2 | 4.2 | 3.8 | 5.2 |
| | min | 0.9 | 0.4 | 0.6 | 0.4 | 0.5 | 0.6 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 1.2 |
| **Cloud (octa)** | Avg | 0.8 | 0.7 | 0.8 | 0.7 | 0.7 | 1.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.8 | 0.8 |
| | max | 1.0 | 0.9 | 0.9 | 0.8 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 1.0 | 1.2 |
| | min | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.1 | 0.4 | 0.6 | 0.5 | 0.5 | 0.6 | 0.5 |

Source: BMKG, 2009

### 3.3 Indonesian house performances

Indonesia has various traditional houses scattered over the whole islands. The ancient houses built in vernacular architectural styles vary from one region to another. The houses have been developed to respond to tropic climate, particularly Indonesia's hot and wet monsoon climate.

‘Most of Indonesian traditional houses are built on stilts, with the exception of Java and Bali. The raised-floor houses has several purposes: it allows breezes to moderate the hot tropical temperatures; it elevates the dwelling above storm water runoff and mud; it allows houses to be built on rivers and wet land; it keeps people, goods and food from dampness and moisture; it avoids mosquito; and reduces the risk of dry rot and termites. The sharply inclined roof allows the heavy tropical rain to quickly sheet off, and large overhanging eaves keep water out of the house and provide shade in the heat. In hot and humid low-lying coastal regions, homes can have many windows providing good cross-ventilation, whereas in cooler mountainous interior areas, homes often have a vast roof and few windows’ (Dawson et. al., 1994).

### 3.4 Acehnese Traditional House

In Aceh, the traditional house is called rumoh Aceh. It has four parts, namely a living room which has no chairs, the middle room functioning as the connection between two bedrooms, the back room functioning as the family gathering room, and the last is the female room which is located either in east or west functioning as the parent sleeping room.

Figure 3.3. Acehnese traditional house (Taqiuddin, 2009)

As the other traditional houses, the house design responds to the local hot humid climate. The responding climatic house designs are as follows:

- The long side with openings of the house facing north and south. It meets the recommended house design in tropics to avoid the direct solar radiation. While the short side facing west and east was a guidance to orient the kiblah (position of Mecca) during prayer which is about $15^{0}$C from west in the clockwise. This reflects the fact that the vast majority of Acehnese people that are Muslims.
- The large overhang along the roof shading the windows and almost all the external wall surfaces facing north and south. This sets the house in a cooler environment. It is even cooler by being heavily shaded by the surrounding trees and vegetation (figure 3.4).

Figure 3.4 Large overhang shaded the windows (Taqiuddin, 2009)

- Raising the floor to up about 1.8 meters above the ground. Besides protecting the occupants against wild animals and flooding, this construction is also intended to catch the higher wind to cool down the air temperature. It is also approached by getting the air from beneath the floor circulated throughout the house through the small air floor gaps. The space beneath the floor is also used to socialize with others and as storage spaces (figure 3.5).

Figure 3.5 Multi function room beneath the first floor (Taqiuddin, 2009)

- Lots of large openings to let the air circulate throughout the house. The apertures are applied in the overall of building envelopes such as roof, wall and floor.

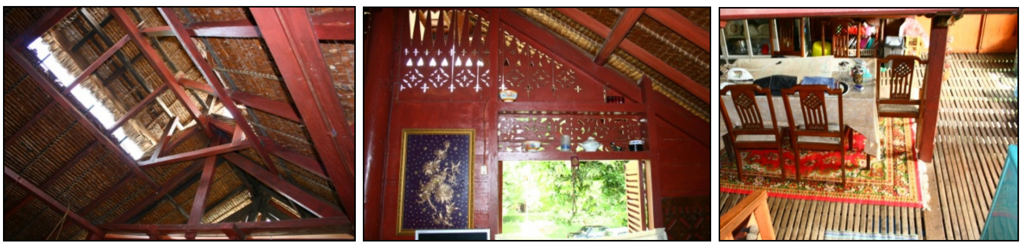


Figure 3.6 Openings (apertures) throughout the building envelopes (Taqiuddin, 2009)

- Limited inside partitions and less furniture to help the air freely circulate.

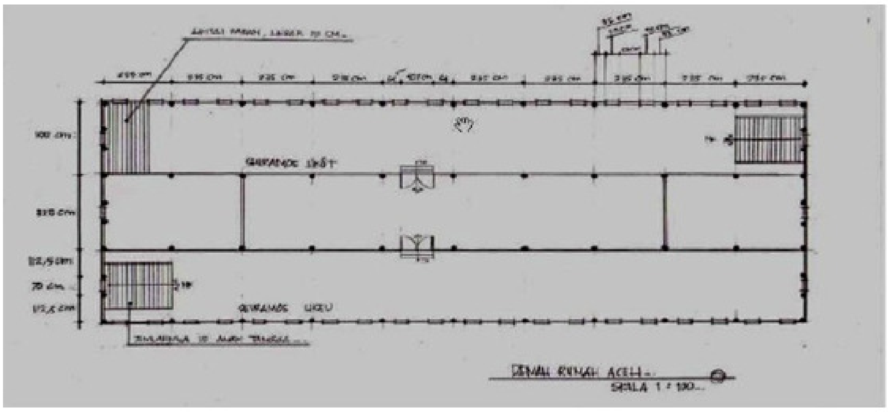


Figure 3.7 Layout of first floor (few internal partitions) (Source: Aceh Heritage Community Foundation, cited in Ibrahim et. al., 2005, p.39)

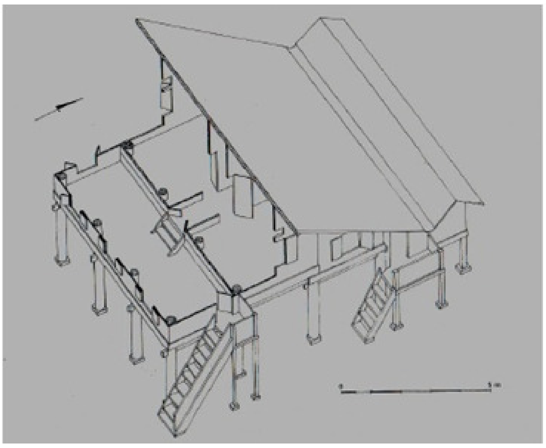


Figure 3.8 Every room is differentiated with varied floor height (Source: Aceh Heritage Community Foundation, cited in Ibrahim et. al., 2005, p.39)

- Built in lightweight construction. Wall is wooden board and roof is made from thatch which is low in thermal capacity.

### 3.5 Current house style

Currently, the Acehnese traditional house is rarely found. The current houses which are regarded as modern houses are built in heavy weight construction. The house type is grounded floor house constructed in brick and concrete wall, metal roof and glazing window. Theoretically, this has high thermal capacity that stores the heat and releases the heat after a couple of hours. The transferred heat during the night can cause an unpleasant internal atmosphere for the occupants. It is even worse during the night where all openings are mostly closed and hence reduce the air speed and increase the air temperature. Nevertheless more people now prefer such construction which shows the modern style living and the more stable performance compared with the light weight house

Figure 3.9. Currently typical house

(Source: Trisnatrinugraha, 2010; and Seputar Indonesia cited in BUMN, 2011)

### 3.6 Building Standards

There are guidelines and legislation that exist in Aceh for the design of building and civil engineering structures, such as follows (Arup, 2006):

- Seismic Design Code

The Indonesian seismic design code (SNI.03-1726-2002) provides an appropriate methodology for designing against the forces of an earthquake.

- Building Regulations

In July 2005 the Ministry of Public Works issued a Building Code for Aceh. This document provides minimum requirements for the design of single storey residential houses termed “dwelling houses”.

- Guidelines

Various UN agencies, NGOs and individuals have prepared guidance documents in a variety of forms targeted at different audiences.

- UN Habitat Check-list

UN Habitat has developed a checklist, which is intended for NGOs, of typical details which are important in the design of new housing

- UN Habitat/Architecture Clinic Comic

This document is intended to provide the community with a walk-through of the house building process. It includes items on defining the hazards, procurement, suitability of materials and construction

- A book was published by MPW of Indonesia about healthy house and environment in 2004. Since that book is (not aimed at specialists) proposed for any kind of people hence it explains in a brief and general way about the definition and the requirement of healthy house and environment, the basic knowledge in constructing houses and the maintenance of house and its surrounding environment. (PERKIM, 2004).

- Larasati (2006) through her academic research provided the guidelines for sustainable housing in Indonesia and used a DCBA scoring method in determining sustainability criteria of houses which include the parameters in the figure below.

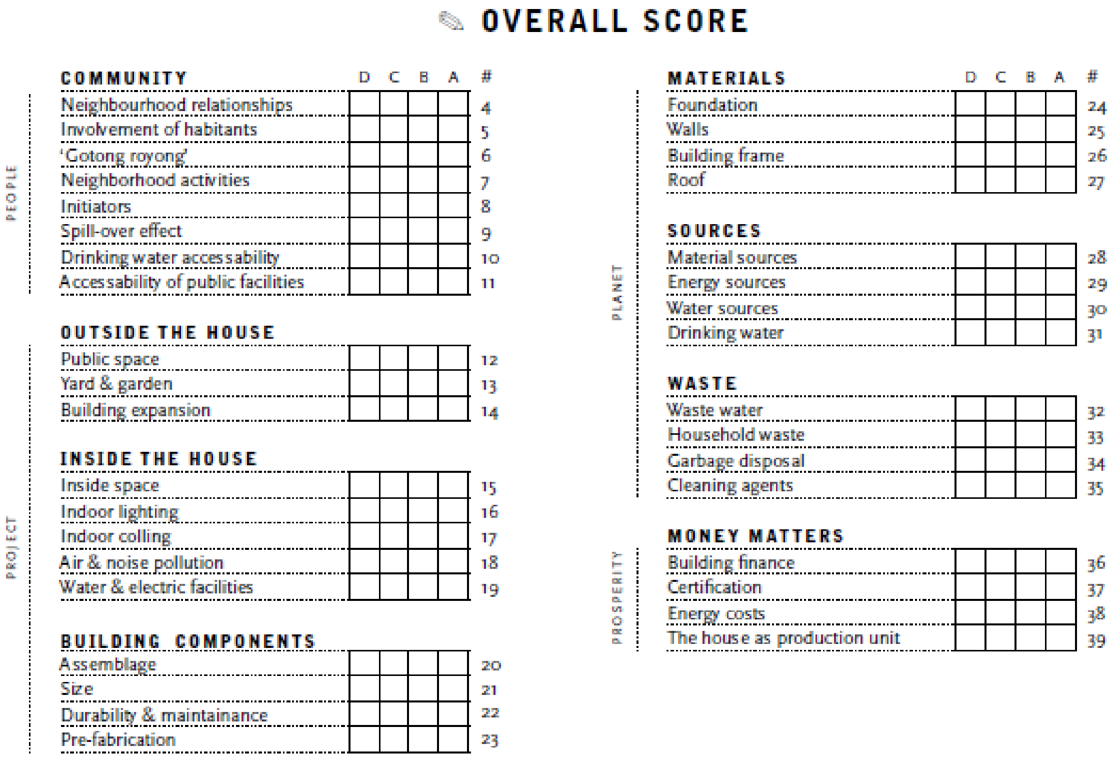



Figure 3.10. DCBA scoring model on assessing sustainable houses in Indonesian case (Larasati, 2006)

The highest score is A and the lowest one is D. But this scoring methodology is believed to be used for individual assessment since it is not published legally by the government yet.

### 3.7. A brief Introduction of Post Tsunami Reconstruction in Aceh

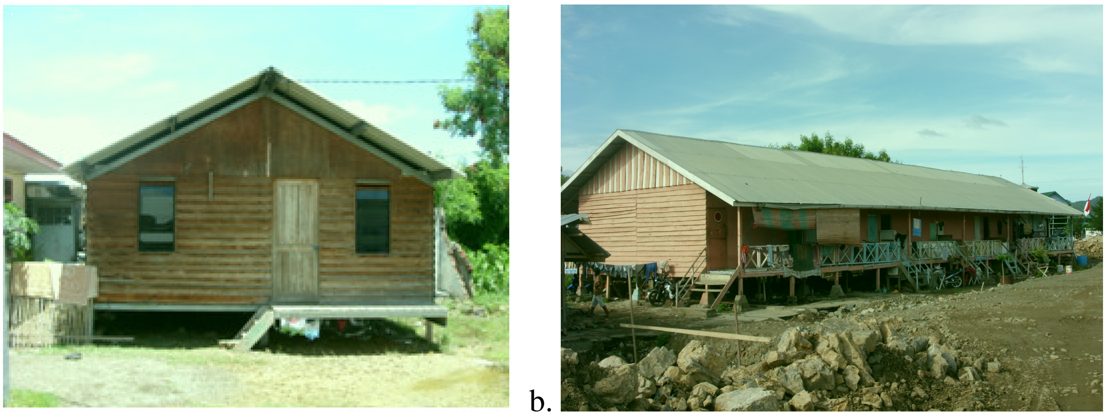
The 2004 tsunami did give significant impacts to Aceh. Apart of the grief conditions as the aftermath of the tsunami such as thousands of displaced people; damaged building, infrastructure and environment; loss of teachers and health care staffs and loss of livelihoods, tsunami also gives positive contributions, namely the signing of a peace agreement in Helsinki between the Government of Indonesia (GoI) and the Free Aceh Movement (GAM) on August 15, 2005, ending a 30-year conflict during which almost 15,000 people had died (BRR and International Partners, 2005). However this is not further discussed since that is beyond this study. In the next subchapter, the post tsunami houses will be merely reviewed since this is the main objective of this study.

### 3.7.1 Post tsunami shelters

Post tsunami shelter was initially begun with temporary tents (figure 3.10). Unfortunately in Aceh, the tents occupied by the victims were the types for use in cold climates and were not comfortable when occupied in a tropical climate. An assessment on thermal performance inside those tents conducted by the Acoustic laboratory found that up to 100 % of occupants were dissatisfied with such conditions, shown with PMV (Predicted Mean Vote) value more than 4 meaning that mostly all the occupants voted the tent as very hot (Zulfian et. al., 2005).

Figure 3.11. Temporary tent accommodation (Steinberg, 2007)

The transitional shelter followed thereafter (figure 3.11). This proposed to give more comfortable living for the victims whilst waiting for permanent houses which could take quite a long time. Barrack-type buildings were one of the types occupied by the victims, and was called 'Huntara- Hunian Sementara 'by the people. It is a temporary shelter built in a long single wooden block divided into many chambers to occupy many households (figure 3.12.b).



a. b.

Figure 3.12 Some post tsunami transitional shelters in Aceh province

The IOM (International Organization for Migration) also developed semi-permanent houses which were made with locally procured materials. These 36 m$^2$ semi-detached moulded concrete units made from cement and wood-framed semi-permanent structures were the result of collaboration between IOM and the Research Institute for Human Settlements of the Indonesian Ministry of Public Works in Bandung, West Java (Relief Web, 2005).

Initially the National Development planning Agency (BAPPENAS), in cooperation with the ministry of Public Works (MPW) of Indonesia coordinated the disaster response for the habitat sector. However the strategy formulation was then handed over to BRR (the Aceh and Nias Rehabilitation and Reconstruction Agency) after the establishment of the agency (BRR) in May 2005 (Steinberg, 2007). There are various organizations either local or international involved in contributing aid and relief for the tsunami victims with some 120 NGOs (Non Governmental Organizations) contributing to housing construction. 'The involvement of these dozens of external agencies could not be overseen easily by BRR itself which later became an overload of responsibilities in the hands of BRR and aggravated the lack of coordination and confusion among the bilateral, multilateral agencies and NGO. Therefore, BRR was practically giving a free hand to all NGOs. 'This condition allowed many NGOs without construction specialization to engage with the housing sector (like Red Cross, Oxfam, Care, German Agro Aid, Muslim Aid, and many others) and some of them failed to come up with quality housing, in terms of good and permanent construction material, earth quake-resistance, complementary services of water, sanitation, roads, etc' (Steinberg, 2007).

Related to the house criteria that were dedicated for the tsunami victims, in January 2005, the central government (through BAPPENAS and MPW which was also recommended by BRR) pronounced the overall policy directive that all eligible earthquake and tsunami affected families/ households would receive a simple 36 $m^2$ house free. But due to the free practice given by BRR, and it might be also due to the flexibility given by the donors after seeing the needs of the victims, the built house areas and designs were of various types.

### 3.7.2 Effect of the post-tsunami reconstruction on the surrounding environment

FAO and ADB estimate that building materials used in the housing construction amount to: 1 million tonnes of cement, 3.6 million $m^3$ of sand, 1.1 billion fired clay bricks, 508,000 $m^3$ of concrete blocks, 87,000 $m^3$ of plywood, 370,000 $m^3$ of sawn timber and 945,000 $m^3$ of fuel wood for brick kiln firing (ADB, 2006). In the aftermath of the disaster, as commonly expected that there have been many influences toward the environment due to the huge reconstruction programs. The scarcity of building materials has gone up with the escalation of prices (Steinberg, 2007; Nazara et. al., 2006) (figure 3.12). Based on World Bank staff calculation, the escalation of construction workers' wages are also detailed in figure 3.13.

| | Cost | End 2004 | Mid-2005 | Early 2006 | Oct 2006 | Change (%) |
|---|---|---|---|---|---|---|
| **Aceh:** | | | | | | |
| Labour | Rp 000 / day | 30 | 40 | 50 | 50 | 67 |
| Wood | Rp million / $m^3$ | 1.0 | 1.5 | 1.9 | 2.2 | 120 |
| Cement | Rp 000 / 50 kg | 20 | 26 | 34 | 37 | 85 |
| Sand | Rp 000 / 3 $m^3$ | 150 | 300 | 300 | 300 | 100 |
| Red Brick | Rp each | 250 | 580 | 700 | 700 | 180 |
| Wall Paint | Rp 000 / 25 kg | 66 | 75 | 90 | 110 | 67 |
| Wood Paint | Rp 000 / litre | 22 | 27 | 32 | 34 | 55 |

Figure 3.13 Rough Estimates of Costs of Labour and Housing Materials in Aceh , late 2004–early 2006 (Nazara et. al., 2006)

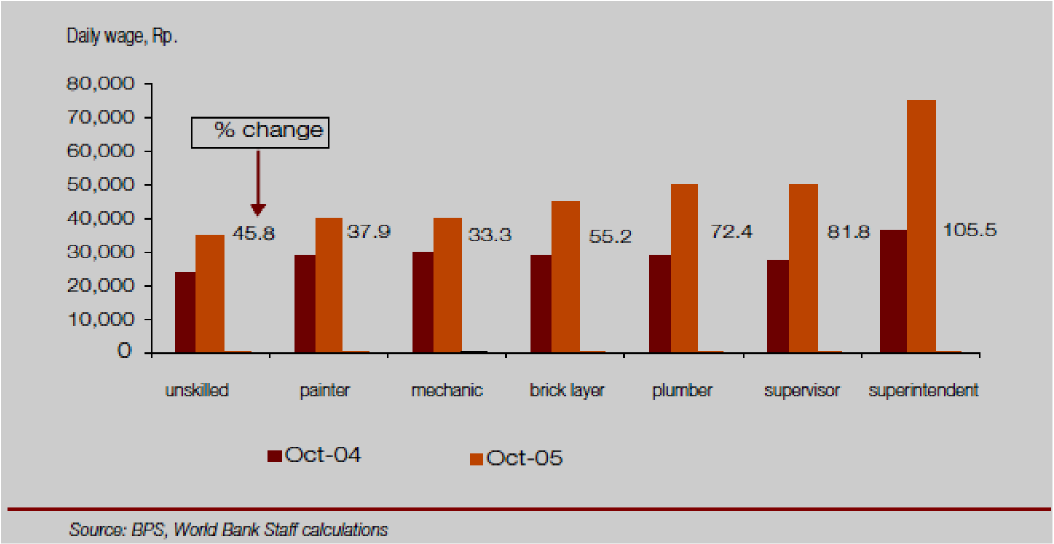



Figure 3.14 Construction workers' wages (the BRR and international partners, 2005)

Another effect due to the reconstruction process is the damaged environment. The extraction of sand and gravel were widely uncontrolled (Bapedalda NAD & GTZ-SLGSR, 2006). This encouraged the change of river flow patterns and threatened to damage major infrastructure along the rivers (UNEP, 2007).

### 3.8 Conclusion

In this chapter, Indonesia was highlighted for its climate and its geography. Following this, Banda Aceh was used as the case study area to describe the relation of climate, house character and building guidelines. Aceh, as situated in a tropical zone, has typically traditional houses suited to that climate. In response to the hot, humid climate of the latitude 5.51 and longitude 95.41, the local houses have large overhangs; raised floors; large openings dominated to face north and south limited inside partitions; and lightweight constructions. Nevertheless, now, people prefer concrete houses due to modern styles of living and their more stable performance compared to the lightweight version.

The building guidelines are quite various and are released by many sources. Even more with post-tsunami reconstruction, many NGOs working on the reconstruction field have created their own guidelines. They are concerned more with construction quality due to the vulnerability of the Aceh location to earthquakes. Post-tsunami houses are quite various, yet the vast majority are concrete houses of around 36m$^2$. The concrete house is dominant as this is the most preferable house among Indonesian people, and it was therefore advised to be built on the post-tsunami reconstruction. The next chapter will discuss the research methodology utilised in this study, including the story of how the data collection was conducted on quite a challenging trip.

# CHAPTER 4 – FIELD STUDY METHODOLOGY

## 4.1 Introduction

To achieve the objectives explained in chapter 1, the quantitative research method is applied. In this study, the research method is conducted by quantifying the research variables shown in figure 3.1. The underpinning philosophy of quantitative research is rationalism (Bernard, 1994) by providing the structured/rigid or predetermined methodology (Kumar, 2005). This chapter thereby presents the research tools including the overview of questionnaires, experimental data collection and building simulation as part of the predetermined methodology.

## 4.2 Field study Methodology

In order to quantify the research variables, the cross-sectional study design is applied in this study. It is undertaken since it aims at finding out the prevalence of post tsunami house performance surveyed at one time. Such study design is useful in obtaining an overall picture as it stands at the time of the study (Kumar, 2005). It is designed to study some phenomena by taking a cross section of it at one time (Babbie, 1989).

The method of data collection used in this study combines the two common two sources, namely primary and secondary sources. The primary sources include surveys, undertaking interviews and questionnaires; measurement using mechanical equipment, and building simulation using TAS building modelling software. Meanwhile the secondary sources are obtained from government publications and earlier research.

The field study methodology as shown in figure 4.1 is explained as follows:

- The objective of assessing the post tsunami houses with respect to sustainability issues is addressed by the survey and questionnaires. To obtain more objective results from the thermal comfort assessment, the measurement of thermal parameters such as air temperature, relative humidity, air movement and quality (through the value of $CO_2$ contamination) inside the house were conducted with mechanical instruments. Day lighting was also measured to determine whether the houses are well lit by the sun during the day.

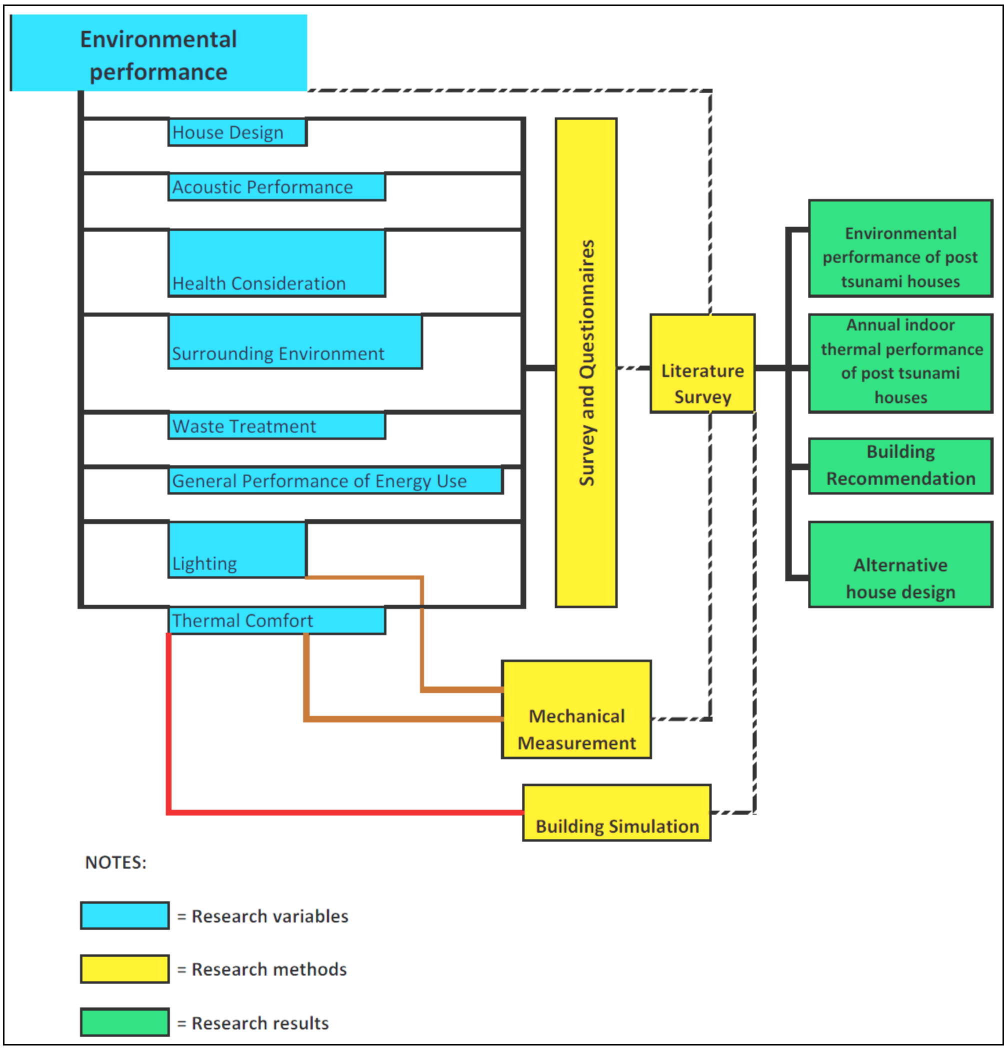



Figure 4.1 Field Study Methodologies

- The thermal comfort assessment was also carried out by using building modelling simulation to support the results of the onsite measurement. The computer simulation can predict the whole year indoor thermal performance based on the outside weather data which can enrich and support the result of the onsite measurement that are conducted in only several months. The performance of proposed alternative house designs were also tested using the building simulation software. The proposed alternative house designs revise the current post tsunami house designs by applying the building design recommendations proposed in this study responding to thermal building design in tropics

- Literature survey as part of secondary sources is used to support and strengthen the overall research process which is finally to achieve the main goal of the study.

- The building guidelines objective is addressed by summarizing the data analysis of both the onsite measurement and building simulation supported by literature survey.

### 4.3 Sample Selection Procedure

This study uses non-random/ non-probability sampling design. This sampling design is actually used when the number of elements in a population is either unknown or cannot be individually identified (Kumar, 2005). In this study the raw actual number of post tsunami houses is published by each NGO and BRR, the bureau formatted by Indonesian government to handle the post tsunami rehabilitation and reconstruction. Nevertheless the numbers vary depending on the source. The problems also occur in the field where some houses are unoccupied. Therefore such sampling design is applied.

Questionnaires used in this study were carried out by interviewing the occupants. The large number of illiterate respondents is usually the reason of conducting the interview during data collection. However in this study it is not the main reason, since the official statistic says that in 2003 and 2004 the percentage of literacy Acehnese people is 96.28% and 95.69% respectively (Data statistic Indonesia, 2011). Asking the occupants to fill the questionnaires and send them back by post is not a common data collection carried out in Indonesia. None of the occupants is familiar with it and hence the response rate will be notoriously low. Therefore visiting the selected samples and carrying out the interview are the applicable ways to undertake. Nevertheless there are still some problems. Visiting the house to conduct the interview during the day is not easy since most of the householders are out at work and so on. Another consideration such as the limited updated data of street maps and addresses direct quota sampling to be applied in the data collection.

The population in this study is the post tsunami houses differentiated by the house donors and locations. The post tsunami houses selected as the samples were determined by simple random convenient sampling. Considering the difficulty mentioned in the previous paragraph, the data collection was carried out by using the available data of house locations differentiated by the selected house providers and sub districts. Each house was approached by seeing the availability of the occupants, since not all of the occupants were at home during the day. The interviewer asked the permission of the occupants to carry out the measurement and required their participation in the survey. If they agreed, then the survey was undertaken either immediately or the day after depending on which of the measurement groups the selected houses is categorized in. If on the other hand they declined to participate in the survey, then the interview move on to the similar house provided by the same provider within the same neighbourhood. In such a way the survey was conducted until the required number of the surveyed houses (quota) is met.

Banda Aceh is the city where the research was carried out. There are approximately 104,287 post tsunami houses that have been built throughout the Aceh province in the 4 years after the tsunami attack in the Aceh province (see table 1.2), whereas in Banda Aceh town the total houses built in the nine sub districts are 18,752 (BRR, 2009). Among the nine of total sub districts in Aceh province, there are five sub districts suffering the worst tsunami effect namely Jaya Baru, Kuta Alam, Kuta Raja, Meuraxa and Syiah Kuala.  A large numbers of houses were therefore built in those areas (table 4.1). In this study several houses in the five sub districts and another one sub district that is Lueng Bata with a large number of houses built are assessed.

Figure 4.2.Tsunami houses in Deah Raya (in Syiah Kuala sub district), Banda Aceh which is sharply surrounded by the sea

In Banda Aceh town there are 41 NGOs involved in providing the post tsunami houses (table 4.2) scattered throughout the 9 sub districts. In this study several houses built by the representative of those NGOs in 6 sub districts are surveyed.

Table 4.1Number of post tsunami housings in 9 sub districts of Banda Aceh town

| DISTRICT | SUBDISTRICT | COMMITED | COMPLETED |
|---|---|---|---|
| Banda Aceh | Baiturrahman | 299 | 247 |
| | Banda Raya | 32 | 32 |
| | Jaya Baru | 3089 | 2949 |
| | Kuta Alam | 3637 | 3413 |
| | Kuta Raja | 2857 | 2805 |
| | Lueng Bata | 779 | 779 |
| | Meuraxa | 6255 | 5973 |
| | Syiah Kuala | 2816 | 2508 |
| | Ulee Kareng | 46 | 46 |
| Total Houses | | 19810 | 18752 |

Source: BRR, 2008

Table 4.2 House donors building post tsunami housing in Banda Aceh town

| NO | PROVIDER | NUMBER OF HOUSES | |
|---|---|---|---|
| | | COMMITED | COMPLETED |
| 1 | Aceh Relief | 91 | 91 |
| 2 | ADECCO | 60 | 60 |
| 3 | Australian Red Cross | 122 | 23 |
| 4 | BAKRIE GROUP | 204 | 204 |
| 5 | CARE International Indonesia | 573 | 373 |
| 6 | CHF International (Community Habitat Finance International) | 157 | 0 |
| 7 | CORDIA Medan | 35 | 35 |
| 8 | CRS (Catholic Relief Service) | 693 | 564 |
| 9 | ELSAKA | 51 | 51 |
| 10 | EPOS Health Consultant | 31 | 31 |
| 11 | GenAssist/CRWRC | 81 | 45 |
| 12 | GITEC | 320 | 320 |
| 13 | Habitat for Humanity Indonesia | 1266 | 1266 |
| 14 | IDB | 175 | 175 |
| 15 | IMM (Istanbul Metropolitan Municipality) | 16 | 16 |
| 16 | IOM (International Organization of Migration) | 369 | 369 |
| 17 | JRS (Jesuit Refugee Service) | 17 | 17 |
| 18 | Katahati Institute | 70 | 70 |
| 19 | Mercy Corps | 10 | 10 |
| 20 | Muslim Aid Indonesia | 176 | 176 |
| 21 | Obor Berkat Indonesia | 80 | 80 |
| 22 | OXFAM | 364 | 359 |
| 23 | PKPU The Humanitarian International | 85 | 85 |

| | | | |
|---|---|---|---|
| 24 | PMI (Palang Merah Indonesia - Indonesian Red Cross) | 555 | 555 |
| 25 | Real Estate Indonesia | 60 | 60 |
| 26 | SATKER ADB | 943 | 943 |
| 27 | SATKER BPPK NAD | 3273 | 3169 |
| 28 | SATKER BRR - BANTUAN PERUMAHAN DAN | 289 | 289 |
| 29 | SATKER BSBT (PP) | 41 | 41 |
| 30 | SATKER MDF | 2619 | 2441 |
| 31 | SATKER NAD | 1197 | 1147 |
| 32 | SATKER WIL 01 | 854 | 854 |
| 33 | Tagana (Taruna Siaga Bencana) | 50 | 50 |
| 34 | Turkish Red Cross | 351 | 351 |
| 35 | UN-HABITAT | 1391 | 1391 |
| 36 | UNI EMIRAT ARAB | 400 | 400 |
| 37 | UPC-Uplink Indonesia | 1015 | 1015 |
| 38 | World Vision | 658 | 658 |
| 39 | Yayasan Berkati Indonesia | 190 | 190 |
| 40 | Yayasan Budha Tzu Chi Indonesia | 718 | 718 |
| 41 | Yayasan Peduli Bangsa | 160 | 60 |
| | total houses | 19810 | 18752 |

Source: BRR, 2008

From the total number of the post tsunami houses, the sample house sizes surveyed in this study is 208 which are met by 95% confidence level. These 208 surveyed houses detailed as in figure 4.3.

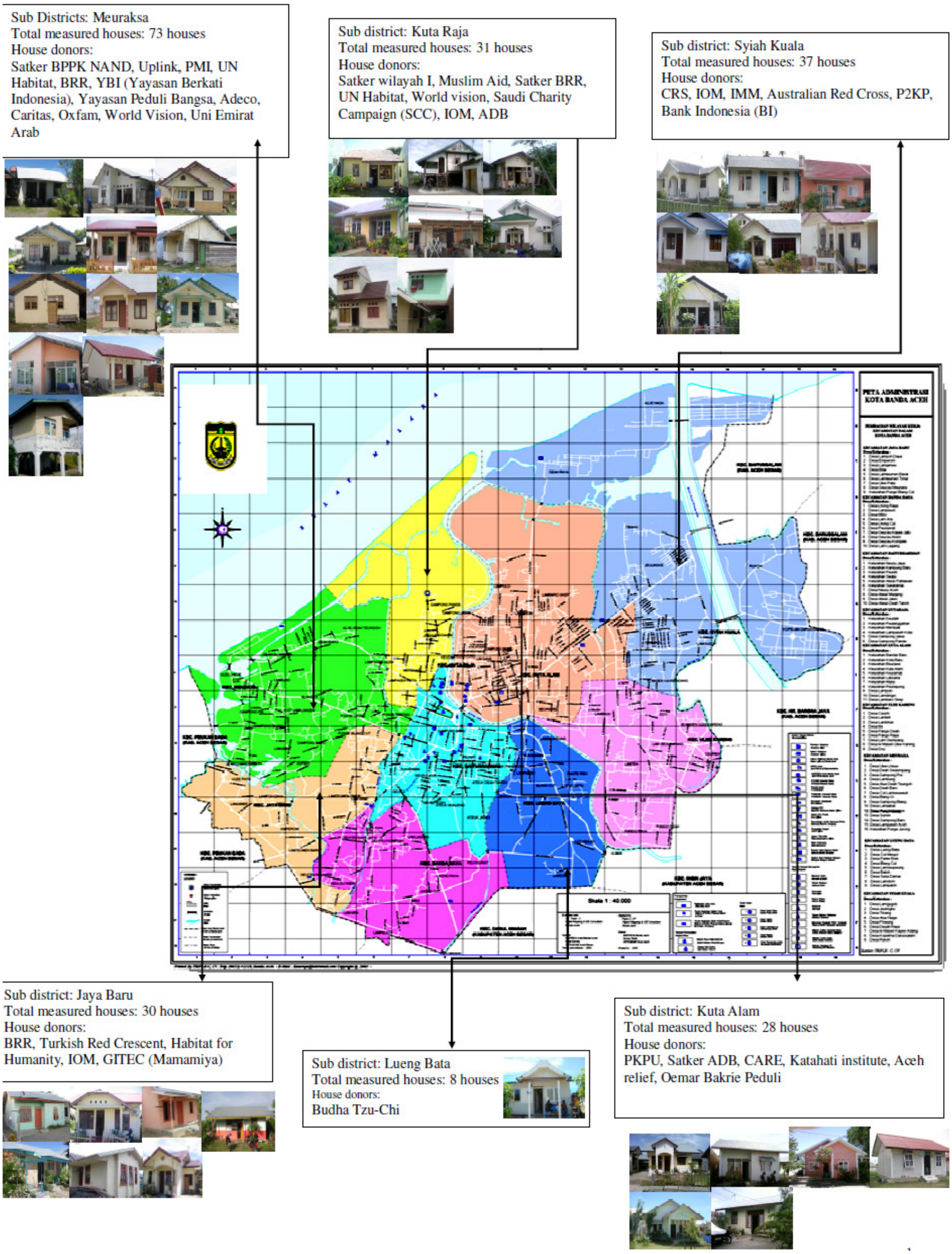



Figure 4.3 The surveyed houses in Banda Aceh

### 4.4 Ethical Issues Considerations

Undertaking the data collection requires the fulfilment of the ethical issues considerations. This study bases those considerations on the Heriot-Watt University regulations. The main issues that should be considered in carrying out the field trip in Aceh respecting the ethical consideration in School of the Built Environments are as follows:

- **Physical hazards:**

**Earthquakes** do not happen so frequent in Banda Aceh. Nevertheless people feel insecure because of it due to the last tsunami and earthquake attack in 2004. This has been responded to by the Indonesian government by providing several tsunami detectors/ alarms located near the sea which can be heard by people from a considerable distance so that they can make themselves safe as soon as possible. This also has been supported by improving escape routes, such as smooth roads to speed removal to safer places. In some places that are vulnerable to high risk of flooding, some of high escape buildings that have been built. The Government has also recommended all new buildings to meet the safe construction standards.

**Flooding** in this place is mostly caused by high frequency and high rainfall. But this affects mostly places that are not supported with good drainage. In addressing out this problem, field trip was conducted in dry season.

- **Biological hazards**

Mosquito bites are common in this place, normally during the night, so every building or house is normally protected with mosquito net. For individual protection, people usually use liquid or lotion to protect the skin from mosquito bites and they are easily and cheaply obtained from any shops.

- **Chemical hazards**

**Contaminated water** means here that all water supplied in any buildings or houses is not allowed to be drunk directly due to its unhealthy quality. People need to cook it first prior the consumption or drink bottled water which is widely sold in any shops.

- **Personal safety related hazards**

Five years ago, this place experienced civil unrest, but the situation is now back to normal. Responding with the safety of data collection process, this process was carried out by approaching the head of some communities to give permission to go into some villages. The local university agreed to provide a formal letter mentioning the legality of this data collection process.

In carrying out the measurement using mechanical equipment, some training was held for participants in using those tools. Households that allowed us to measure their house had the measurements explained and we requested their cooperation in taking care of the instruments. The equipment was located in a safe place during the measurement process and has been identified to contain no poison or have any harmful impact.

- **Environmental impact related hazards**

Rubbish and pollution have been a normal view due to peoples' daily habit. But currently it seems that peoples have been starting to understand to take care of their surrounding environments. In this field trip, all participants are recommended to get their foods from clean shops.

- **Emergency procedures**

In this field work we conducted questionnaires and carried out measurements using mechanical equipment in private houses. This work was carried out in such as was that the participants faced no danger. Participation was well explained to speak nicely to peoples and not to compel peoples either to answer or to let data collection participants measure their houses. In case of any unexpected things happen, during the measurement process participants was contacted frequently in order to know how far the process is going on and if any problems they are having. Since this field work will legally comply with local university and community leader's permission, any permissions or security problems will also be under their responsibilities.

This study will not cause any harm either for the interviewer or the interviewee. Nevertheless payment and non-payment of participants will influence this study. It is normal in this region for those participating in such a survey and monitoring exercise to receive some small recompense by way of thanks. Since this survey includes some thermal comfort assessment conducted in houses for two days and for some other houses for four weeks, this survey is designed to provide a small fee for households/ participants. It was made clear that this was not affected by the answers given to the questionnaire, and that anonymity was guaranteed. Participants were also advised about the assessment conducted and their collaboration in taking care of the instruments.

In dealing with those issue considerations, the writer began the data collection by approaching the local university "Syiah Kuala University" to participate in this work.

The head of Architecture department of Syiah Kuala University welcomed this work and the writer was able to obtain a formal letter and to ask some students to help to conduct this survey. After obtaining the letter from the university, the writer also went to some sub district offices in Banda Aceh to inform them that the writer and the team would visit and do the survey in the selected sub districts in Banda Aceh where huge numbers of donated houses for tsunami victims had been built. It needed about two days to get the reply from them mentioning that they would allow us to do this work.

There were 10 (ten) students participating in this survey. The writer trained them to work with the questionnaires and do the survey by considering all ethical issues for about two days (May 18$^{th}$-19$^{th}$, 2009) (picture 4.4).

Figure 4.5. Short training for the students participating in this field work

This survey was a significant piece of work and needed a substantial effort. 10 students conducted the survey in up to 208 households. They visited each house that had been selected which was registered in BRR (a national bureau working on reconstruction and rehabilitation in tsunami affected areas (Aceh and Nias). It was not an easy work, since they also needed to measure the thermal parameters both in living room and bedroom for one hour. Hence, to meet the requirements of ethical considerations, the survey was only carried out where the household welcomed them and had time to answer the questionnaire and let them come in to their bedroom as well.

For these 208 households, small gifts were given to thank them for their cooperation. These gifts were lantern/ torch completed with batteries, electric protection against mosquitoes and a mobile bag which can be utilized as a purse (figure 4.6). These gifts were chosen since these are the equipment most needed at home. In Aceh, it is very common that the electricity is off for more than 3 hours per day, which of course is difficult for people if it happens during the night, hence the lantern became a welcome gift.


Figure 4.6. Gifts (torch, mosquito electric protector, mobile bag/ purse)

Since Banda Aceh is located in a tropical country, mosquito bites are also very common, particularly during the night. Hence electric protection against mosquitoes was also well appreciated by the households. There were also some houses measured for two days or even more which were provided with an amount of money as the gift (IDR 80,000.- IDR 200,000.-). This was aimed to enable them able to buy their daily needs, the amount being enough to buy a sack of rice which would last for about two weeks.

During the field work, the Acoustic laboratory of Syiah Kuala University, which is one of the outstanding laboratories in Indonesia working in the environmental field, had kindly given the place for my work as the base camp, the place for training the students and the space for keeping all of field work equipment. There were also Mr. Tri Harso Karyono, a professor from Tarumanegara University and Mr. Zulfian, the director of Acoustic laboratory of Syiah Kuala University who had given contributions in giving me more guidance in this field work.

Figure 4.7. From left: Mr. Tri Harso karyono, writer, Mr. Zulfian's wife and Mr. Zulfian in School of Architecture of Tarumanegara University, Jakarta

### 4.5 Data Collection

Data collection was carried out from May 11$^{th}$ to July 19$^{th}$ 2009. The data collection is divided in to two groups explained as follows:

**Group 1**

20 houses from those sub districts were surveyed with questionnaire and measuring equipment for 2 days each. In order to provide a good comparison three existing houses which were not destroyed by the tsunami as well as another newly reconstructed house and one Acehnese traditional house were measured for 40 days. The houses selected are convenient sample since the measurements for those houses were taken over a longer duration than the other 20 houses, hence easy access to those houses was be obtained by selecting previously known households (Mugo, 2002).

**Group 2**

Another survey carried out with questionnaires and one hour measurement during morning and afternoon was also conducted involving up to 208 houses in several sub districts in Banda Aceh. This is done so as to understand the general performance of house quality and people's satisfaction with their houses related to environmental issues.

### 4.5.1 Questionnaire

The first tool of the survey was the questionnaire which was carried out by interviewing the house occupants. The question type was designed in close ended question selected which was not only to allow easily analysis but also to help the interviewee to answer the questions, since most of the questions refer to the building construction, and some terms may be unfamiliar to them. The primary language used during the survey was Indonesian. Some respondents prefer to speak the Acehnese local language even though they actually can speak Indonesian. Therefore most of the interviewers are selected were also able to speak the local language.

The questionnaire (see appendix A) has eleven pages divided into sections explained as follows:

**Section A: House description**

This concerns the house description including location, house area, number of rooms, number of occupants living in the house, and other questions associated with house type.

**Section B: House materials**

The questions in this section are about the building envelope materials. This will be associated with thermal comfort analysis.

**Section C: Thermal comfort**

The questions are asked about the thermal sensations of the occupants during all days. During the one hour interview, the inside air temperature is also recorded in every 10 minutes interval.

**Section D: Lighting**

This section includes questions about the day lighting quality subjectively based on the occupant's feelings. The types of lamps used in the surveyed houses are also asked. The illuminance in the living and bed room of the twenty post tsunami houses are also recorded.

**Section E: General acoustic performance**

This section includes questions about the noise that may affect the occupants, subjectively based on the occupant's feelings.

**Section F: Environmental/ surrounding assessment**

The questions are asked about the house surroundings and the vulnerability of the house location to flooding.

**Section G: Water and waste treatment**

The questions in this section focus on how the waste, grey and black water in post tsunami housing are treated. Clean water provision is also included.

**Section H: Access to local facilities (between 500 m- 1 km from the neighbourhood)**

This concerns the proximity of local facilities to the post tsunami housing area

**Section I: Health consideration in houses design**

Questions are asked in this part about the health of the occupants and which is related to the building materials

**Section J: Energy assessment**

This study asks about how the occupants use the fuels such as electricity, gas and kerosene, determined by the monthly bills.

**Section K: General perception on this house**

The questionnaire is concluded by asking the general perception of the occupants toward the overall performance of the house.

Some questions in the sections on house description; house materials; water and waste treatment; and access to local facilities are adopted from questionnaires used in post tsunami house monitoring held by UN Habitat and Architecture department of Syiah Kuala University in 2006-2007.

### 4.5.2 Interview

Not all of the households welcomed the team since there had been many surveys conducted by various organizations or other councils after they occupied their house. Their visits had actually given the households hopes that they would sort their financial problems out. Yet, their visits were mostly on research work that did not provide such support, and which might make them dissatisfied and feel that it was an inconvenience.



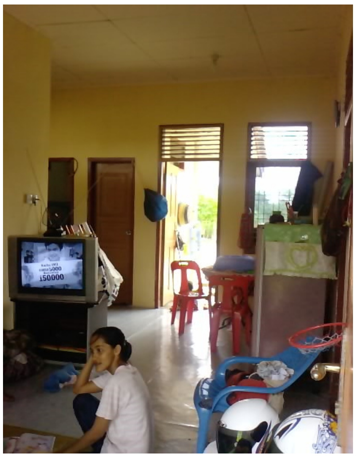













Figure 4.8. The way of the household welcomed the interviewer and answered the questionnaires

Nevertheless, several households gave a warm welcome and even offered the teams lunch in their house and gave them refreshments during the survey process. Most of the households who let the team in could answer the questions while some others needed further explanations. The households were asked to continue with their normal activities during the survey as we did not want to interrupt their daily activities due to our survey (Figure 4.8). In spite of this welcome, there were some households who asked for help such as money or whatever to support their life since a few of them live in poverty. But we explained that this survey was only an academic activity purpose which did not provide such supports. Yet, our gifts were gratefully accepted (Figure 4.9).

Figure 4.9. The household accepted the gift after the interview

#### 4.5.3 Experimental Data Collection

The other main activity of the teams besides conducting questionnaires was the measurement of thermal parameters. The equipment and the method used in conducting the measurement are described in table 4.3, figure 4.10 and 4.11.

a. Lux meter, air velocity and temperature meter, CO2 meter and mean radiant temperature meter

b. Thermal comfort data logger

Figure 4.10. Measuring equipment utilized in the survey

Table 4.3. Measuring equipments

| **Parameters** | **Method** | **Equipment** | **Interval (min.)** | **Lay out** |
|---|---|---|---|---|
| Inside air temperature and relative humidity | The logger collected data over two days in both living and bedroom | 295-061 ThermaData humidity logger - model HTB | 10 minutes | The loggers were located 1-2 m above the floor (body-head height) in a secure place to avoid them being disturbed by the occupants during the 2 days data collection. |
| Surface temperature | Collecting data manually over one hour during morning and afternoon | Minolta/ land (infra red- mean radiant temperature meter) | 10 minutes | |
| Air velocity | Collecting data manually over one hour during morning and afternoon | Testo 415 (Temperature and air movement meter) | 10 minutes | This measuring equipment was held manually to measure the data in living room, bed room and kitchen. |
| $CO_2$ contamination | Collecting data manually over one hour during morning and afternoon | Testo 535 (CO2 measuring equipment) | 10 minutes | |
| Indoor illuminance | Collecting data manually over one hour during morning and afternoon | Testo 1330 (Digital lux meter) | 10 minutes | |

The thermal measuring process was conducted utilising the equipment described in table 4.3 The only tools left in those houses over 2 days to measure the thermal parameters were thermal data loggers. These are quite small and are good for survey work, but still needs the householders' cooperation to avoid damage. The householders whose houses were surveyed contributed very responsibly in looking after it during the two days measurement. They were located in a secure place and on the recommended position of the thermal comfort measurement.  The remaining tools such as manual temperature and humidity meter, light meter, air velocity meter $CO_2$ meter were only used over several hours by the surveyor and taken home after the measurements.

The measurements were carried out in several rooms, such as living room, bedroom and also kitchen for $CO_2$ measurement case. It made the survey rather difficult to do since some peoples did not let the surveyors come into their bed rooms. This problem was one of the difficulties making the survey time extended. In sorting this problem out, two additional students were asked to participate to accelerate the field survey. So there were 10 students in total participating as the surveyors in this field work.

Figure 4.11. Measuring process

### 4.6 Dynamic Thermal Building Simulation

In this study, the dynamic thermal building simulation software TAS was employed for the prediction of the thermal environmental performance within several types of post tsunami housing as the representative of building samples used in this study. In particular, this dynamic thermal modelling software was utilised to model the indoor thermal performance in free running buildings.

The research project employs TAS in three stages. First, it simulated five samples of post tsunami house models. It aimed at seeing how the annual indoor thermal predictions in the house differ from each other, since the five house models were characterized by different house designs (including house construction and building materials). In this stage, the same objective was also conducted to Acehnese traditional house. This aims at seeing how far the indoor thermal performance has been shifted from the traditional house to the current ones.  The second stage was undertaken to simulate some simple models applying some house design variables to find out the best way to reduce inside air temperature. The third stage utilised TAS to simulate the propose house models applying the house design variables as the final objective of this study. In this study, TAS is employed only for the prediction of annual indoor thermal performance shown in hourly records. Besides showing thermal parameters such as air temperature; relative humidity; air movement and mean radiant temperature, this study also employ TAS to show thermal mean vote (PMV) and dissatisfaction upon indoor thermal performance (PPD).

### 4.7 Conclusion

This chapter discusses the research methodology utilised in this study. The cross-sectional study design was applied by using the survey, questionnaire and field measurement to collect the data. Data collection was carried out from May 11$^{th}$ to July 19$^{th}$ 2009. The total number of surveyed houses was 208. 188 houses were surveyed with questionnaires; and another 20 were measured in more detail using mechanical equipment. The survey was helped by local university students visiting the survey participants (post-tsunami house occupiers) from door to door. Small gifts were prepared for the participants for being involved in the survey.

Another central work in this study was building a simulation which utilised TAS building simulation software. TAS is used to predict the annual indoor thermal performance of some selected post-tsunami house designs, representative of the 208 surveyed houses. The next chapter will analyse the results of the questionnaire answers focusing on environmental aspects.

# CHAPTER 5 – DATA ANALYSIS OF POST TSUNAMI HOUSINGS ENVIRONMENTAL PERFORMANCE BASED ON QUESTIONNAIRE

## 5.1Introduction

In this chapter the data obtained from the questionnaires dealing with environmental performance are analysed. First, the post tsunami houses are analysed through the house types, house occupancy, house design, and house materials. Further lighting and acoustic performances in the houses are described. The surrounding performances are analysed from flooding, vegetation provision, water supply, waste treatment, and access to public services. Finally the energy use performances in the houses are simply analysed through the power supply and the monthly average usage of the powers. The overall satisfactory of the householders is also shown as the closing analysis. The analyses are carried out simultaneously after the data are presented.

## 5.2 House Description

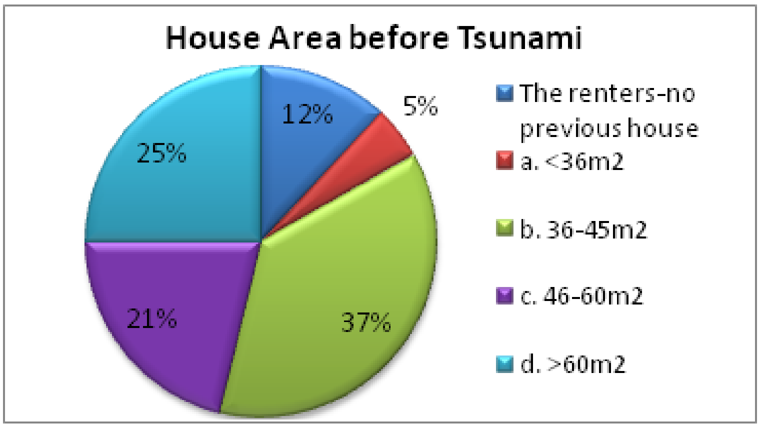
Post tsunami houses built by donors are categorized in to three main types as mentioned by Arup (2006), namely:

- The "permanent" houses, which are built from brick, often with reinforced concrete frames, this house type is also known as heavy weight house.
- The "semi-permanent" houses, which are built from brick and timber and commonly known as half permanent house.
- The "traditional" houses, which are timber structures grouped in to light weight house.

In this study, 208 post tsunami houses were surveyed consisting of 81.7% of heavy weight; 10.6% of light weight and 7.7% of half permanent houses. This number came from the actual large number of heavy weight houses and quite small number of light weight houses built by donors. Boen (2006, 2010) confirmed that people in Indonesia tend to upgrade their timber houses into masonry because a measure of status is associated with the owners of such masonry houses. As it becomes a "new culture" and preferred all over Indonesia, this is also becoming an advisable house type to be constructed in Aceh.

### 5.2.1 House occupancy

As explained in sub chapter 3.7, the Indonesian governments gave a simple 36 $m^2$ house to families/ households free. But due to the free practice given by BRR, and it might be also due to the flexibility given by the donors after seeing the needs of the victims, the areas and designs of the houses that were built were of various types (figure 5.1.b). This can also be understood as the way to be fair with all the tsunami victims, even though the majority of the house occupants had much bigger houses prior to the tsunami (figure 5.1.a).

a. 

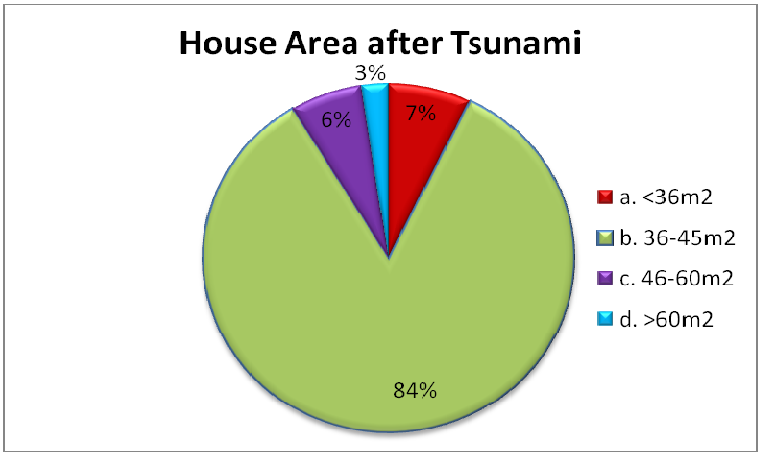

b. 


Figure 5.1 Comparison of house area before and after tsunami

Aceh building code provides the minimum size and space required in dwelling case which is $36m^2$ and $9m^2$/ person respectively. BRR, a trusted organisation in rehabilitating and reconstructing Aceh after the tsunami, also used this standard by adding the area of kitchen and shower room/ toilet hence it becomes around 36-45 $m^2$. In this study 206 out of 208 houses are valid in terms of space requirements as shown in table 5.1 below:

Table 5.1 House occupants

| House size | Mean | N | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| a. <36m2 | 4.1333 | 15 | 1.18723 | 2.00 | 7.00 |
| b. 36-45m2 | 3.7283 | 173 | 1.39815 | 1.00 | 8.00 |
| c. 46-60m2 | 4.3077 | 13 | 2.42846 | 1.00 | 8.00 |
| d. >60m2 | 3.4000 | 5 | 1.34164 | 2.00 | 5.00 |
| Total | 3.7864 | 206 | 1.46604 | 1.00 | 8.00 |

Table 5.1 shows that the average number of people living in the post tsunami house sized <36$m^2$ to >60$m^2$ is 3.7~4 persons even though the maximum range reaches 8 persons per house. However figure 5.2 shows that about 88.8 % of post tsunami houses are occupied by 1-5 persons which can be said to meet the dwelling space standard.

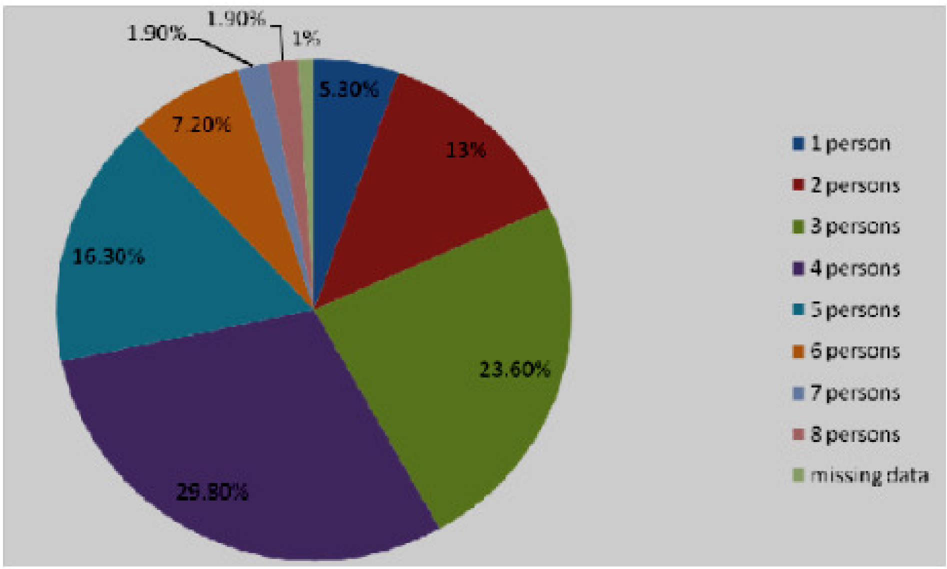



Figure 5.2 Percentage of house occupancy

### 5.2.2 House design

House designs are actually influenced by the surrounding environment, such as the seismic area and the closeness to the sea or water surface. In this study three main types of houses are found in the following percentages:

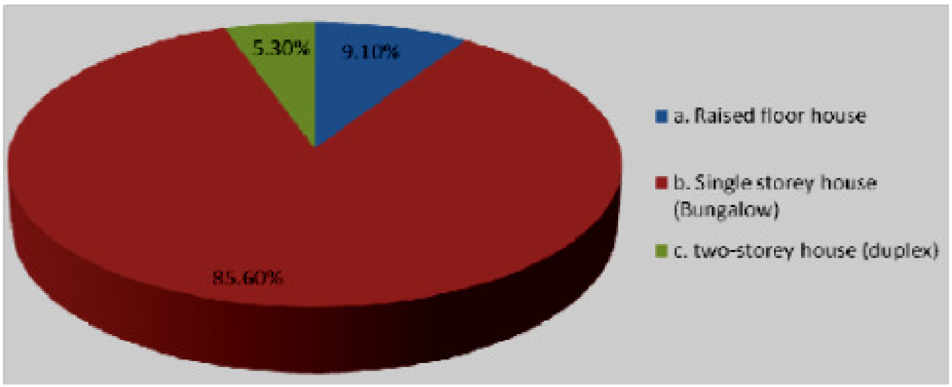



Figure 5.3 Post tsunami house types

The raised floor houses were found to be located roughly near the sea, however several single storey houses (bungalow) which were (85.5%) dominating the house type were also built close by the coast line. It seems that there was no strict rule in building particular house types in relation to their environment.

Following the tsunami, it may be asked why people were still permitted to build houses around the coast line. Kuntoro Mangkusubroto, the leader of BRR argued that there were actually two conceptions - either to ban the people from returning to dangerous areas, or giving the people the right to choose where they want to live and the government will gradually educate them. This last choice was preferred, considering that the tsunami victims lost everything except their lives and land, and prohibiting them to go back to their land could be troublesome (BRR, 2006).

From the survey, we see that the choice of house design is determined as shown in figure 5.4. Option a, b and c which seek to express the people's wills are about 49.6%, against option d and f, the provider's choice at about 33.7%. This may be the reason for having single storey houses (bungalow) also built around the coast line since this is the dominant house design currently preferred by the local people. About 16. 3 % mentioned 'not known' with regard to the house design, which is mostly expressed by the renters or the occupier that previously did not live in the house area (not the landlords' statements).

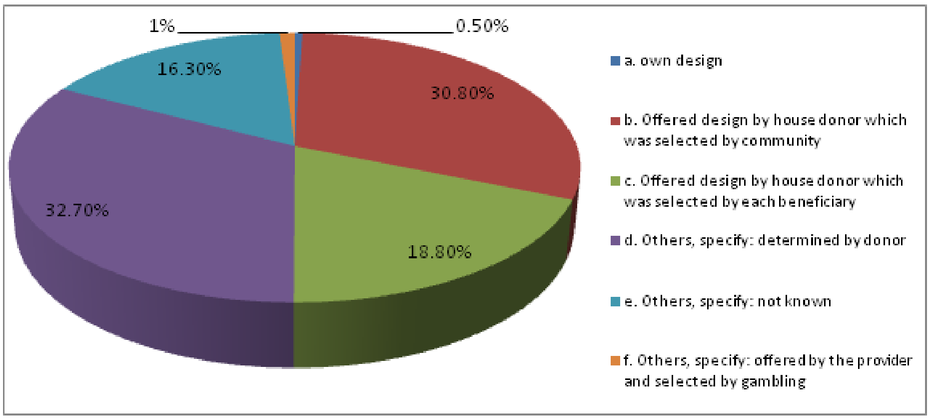



Figure 5.4 House design determination

The house area of 36-45 $m^2$ is normally designed with two bedrooms (9 $m^2$/ room) and an open plan living room and dining room (18 $m^2$), and added with one toilet. In only 40.4% of the houses, providers built the kitchen while another 59. 6% of houses were built without kitchen. This means that some householders have to add more rooms to make more space for their daily activities. 46.2 % of house holders added kitchens, 12.2% added toilets, 14.5% added more bedrooms, and 12.1% built other rooms such as living rooms and storages.

## 5.3 House Material

### 5.3.1 Roof

The roofs of permanent post tsunami houses are pitched roofs - 76.9% are covered with zinc, followed by other metal (21.2%) and asbestos (1.9%). These three main roofs are 76% left unpainted (their original colour) and another 24 % variously painted with green, blue and red.

The majority of the ceiling covering the roof of the post tsunami houses is ply wood (78.8%); 10.2% is variously with gypsum, GRC and calsiboard; 4.3% of houses are without any ceilings; 2.9% is with asbestos as many as plywood covering the zinc insulated with aluminium foil; and about 1% with plastic sheet and the aluminium foil insulating the zinc. 89% of the ceilings use plywood, gypsum and any other boards can be said to meet the standard of ceiling recommended by the Aceh building code and the UN Habitat construction guidance. However a small percentage use no ceiling or use inappropriate material such as plastic sheet and asbestos, and this will make people automatically uncomfortably hot due to the lack of thermal mass of the ceiling; additionally asbestos may cause the health problems related to sick building syndrome. 72.1% of those ceilings are painted in white; 21.6% are painted in various light colours such as blue, cream, green, orange, pink and maroon; and 6.3% are left unpainted.

### 5.3.2 Walls

In these 208 houses, 68.3% of houses are built with 15cm bricks plastered with cement; 11.5% concrete brick plastered with cement; 7.7% built in half permanent construction (cemented brick combined with timber); 2.9% built with GRC board with insulated cavity; 1.9% built with hollow block; and 12.5% built variously in small numbers with calsiboard, GRC board and asbestos (light weight materials, 5m thick). 61.5% of internal walls are built with plastered brick, 11.5% with plastered concrete brick and another 27% are built variously in small numbers with the light weight materials such as GRC board, asbestos, calsiboard and the half permanent construction (wood combined with the plastered bricks). Those both wall surfaces are mostly painted in light colours, such as white, cream, light green, light blue and any other light colours.

### 5.3.3 Floors

Floors are 54.3% cement plaster, 38.9% are ceramic tiles and another 6.7% are wood. The houses are 68.8% mostly built lower then 50cm above the ground surface. 22.1% are built in between 50-100 cm and another 9.1% are raised floor houses with the height of more than 100 cm above the ground surface. The houses built more than 1 meter above the ground level are quite reasonable because its location about 600 m from the coast line. However several houses built less then 50cm or in between 50-100cm above the ground level are also built just about 0.9 -1.3 km from the coast line which may be the result of what the the leader of BRR argued with regard to the permission for people living near the coast line.

### 5.3.4 Openings

Windows as the opening type in letting the air flow in to the room were mostly designed in single glass framed in wood (92.8%); 3.4 % were built with wood which was applied in traditional house resembling built by Muslim Aid; and another 3.8% were single glass with aluminium frame. The thickness of the glass is mostly less than 5 mm. Window area is 0.5-1.5m$^2$ per 9m$^2$ of floor surface which are 87% were designed in awning types; 7.2% casement; 4.3% louver; and another 1.5 % is the combination of awning and louver; and awning and fixed.

Doors are single doors using materials that are just the same as other door materials commonly used in Indonesia, which is constructed with wood [(2000,2100,2400 mm) x (800,900, 1200 mm) for one single door (PU), (SNI, 1989)]

Post tsunami houses were built of various orientations with the openings such as doors and windows, especially in the living room, were oriented in any direction. In theory, Buildings should orient their openings to south or north to avoid overheating; nevertheless it seems to be difficult to apply due to the limitations of the surroundings. 83.7% of house fronts were oriented variously to south, north, west and south while 13.9% were oriented in small numbers to south-east, north- east, south-west, and north- west. The relation between the aperture orientation and inside air temperature is explained in sub chapter 6.7.

### 5.3.5 Columns, foundations and roof structure

Columns, foundations and roof structures could not be observed during the survey, since all of the houses have been occupied and there were no more ongoing house constructions carried out. These structures are the most important ones in supporting the house load and stability in case of earthquake. There are some institutions conducting the survey with regard to this aspect, such as follows:

1. ARUP (2006), which carried out their works shortly after the house construction for the tsunami victims just began. The focus of benchmarking was whether, both in terms of design and construction quality, and whether this resulted in an earthquake resistant house. They concluded their works as follows:

- Most houses are built in 36m$^2$. Some of them have veranda or kitchen extensions.

- The houses are constructed in permanent, semi permanent and traditional (timber) houses.
- The quality of the design and workmanship of permanent houses which are constructed from in-situ reinforced concrete frames with brick infill with the exception of the CRS house was poor. The CRS house uses the similar construction methodology but is well supervised to assure that the quality of construction meets the design criteria.
- Various construction methodologies such as pre-cast frames, and reinforced blockwork have been used for permanent houses. These structural systems have all been developed by experienced engineers, to withstand earthquakes.
- The lightweight construction such as semi-permanent and traditional housing will probably meet life safety criteria. Nevertheless there was evidence of other problems including leaks due to poor workmanship or timber shrinkage, and termites.

2. UN habitat and the Architecture department of Syiah Kuala University carried out the survey with regard to the house construction in 2005-2007 to several districts in Aceh affected by tsunami. They assessed the general performance of post tsunami houses in terms of construction quality, flood safety, satisfaction with organisation, and expected lifetime of the house. From about 300 houses donated by 61 donors in all over Aceh surveyed by them, the average score for the house construction quality is 2.8, with maximum 4 and minimum 1.8. The score is ranged from 0-4 where 0 equals to unacceptable, 1 is poor, 2 is mostly acceptable, 3 is mostly good and 4 is all good. There were only 3 NGOs obtaining the score above 3 namely Emergency Architects, Atlas Logistique and Care; and BRR contractor. Such score refers to mostly good and the house meets the building code (UN Habitat, 2006).

### 5.3.6 Building material sources

88.4% - 96.6% of the survey participants do not know where the building materials are from. The remaining which is about 3.4-11.6% confirms that most of the materials such as timbers, soils, stones, aluminium, glasses, stones and cements are produced locally in Aceh and another 1-2.4% are imported from outside Aceh.

a. Wood

With regard to wood supplies, there was a preliminary assessment of the volume of logs required to provide temporary barracks, accommodation, low cost permanent housing, reconstructions and repairs of office buildings, schools, hospitals, and any other shelters. The amount of wood required for houses or building with higher timber contents is about 6.6 -7.9 million $m^3$. If it is assumed to have the construction periods in over the next five years since from 2005, it means that the average log requirement is between 814,497- 1, 58 million $m^3$ per year (Greenomics Indonesia, 2005). There are some possibilities in meeting the amount of timber assessed in that study, those are:

Table 5.2 Alternatives of timber sources

| Timber sources | Assessment |
|---|---|
| Stolen, found, seized and donated timber | Limited number so that unlikely to be significant source (Greenomics Indonesia, 2005) |
| The use of timber from Aceh's production forest | The legal quota of timber allowed by the ministry of forestry is only about 50.000$m^3$ (Greenomics Indonesia, 2005) |
| The use of timber from timber plantations | Insignificant since the demand for wood industry processing is higher than the natural forest could supply (Greenomics Indonesia, 2005) |
| The use of timber from community owned forest and crop plantations | Insignificant since this way just could provide 0.46%-1.79% of the total raw timber demand (Greenomics Indonesia, 2005) |
| Recommended Alternatives | |
| The use of imported timbers | Being negotiated between government and donor state, so the timber can be made available free of charge. However, there are some problems related to this way such as the unavailability to get the timber quickly since need to pass the importing procedure, nevertheless the timber quality is much better in |

| | |
|---|---|
| | term of the strength and quality (Greenomics Indonesia, 2005) |
| The use steel trusses (or steel high-pitch roof), windows, doors and ventilation frames (Zuo, 2006). | This alternative still meet the problem regarding with the high producing price; nevertheless it can be reduced if all the reconstruction agencies with same intention in Aceh organize their individual requests into a big order and choose both local and international companies with reliable reputations for a competitive tender for mass production |
| The use of coconut trees as structural component as replacements to timber products (Zuo, 2006). | As palm or coconut trees commonly grow in Aceh, it can be used as an alternative. It is sound for structural properties, Another advantage is as the coconut palm is branchless, and palm wood is free from knots, which makes it an ideal timber. However if palm trees are used in large amounts, the natural provisions will be shortly scarce and damage the environment if there is no simultaneous replanting |
| The use of bamboo trees | Bamboo can grow easily in many parts of Indonesia. Actually it has been be used as building material, furniture etc for centuries in Indonesia. However the inferior social status of bamboo discourages people to use it widely (Larasati, 2006). In Aceh, even though bamboo can grow, it is not cultivated nor applied as building construction. Bringing the problem of timber scarcity, bamboo can be the alternative to be planted shortly to accommodate any future need of woods (long term actions) (Bambu Nusa Verde, 2011). Rapid growth of bamboo ensures the continuity to meet ongoing needs. |

b. Bricks

Bricks either built in clay or concrete were used in large amounts during the construction recovery after the tsunami. The brick demands were then met by training the tsunami victims (local people) to make bricks using the local materials. Many NGOs carried out those programs such as DIES Batako, a local NGO, specialising in brick-making training, founded in Banda Aceh through ILO funds (UNESCO, 2006) and Architecture clinic (ARCLI, 2006) which really helps to meet the need of brick demands.

There were some new alternative bricks apart from the conventional bricks advised to used in post tsunami reconstruction (Arcli, 2006), such as

- ✓ Bataton

  Bataton is the abbreviation of Bata Beton or concrete brick. The brick with the cavity inside is made from a mixture of cement, aggregate, sand, gravel, water and other special materials. These materials are printed in various forms which later are named as bataton. Bataton is produced by Holcim and published by Arcli (Architecture Clinic) to be used on post tsunami construction.

- ✓ Compressed Earth Blocks, or CEBs

  Compressed Earth Blocks, or CEBs, are construction blocks made with clay, sand, and a stabilizing ingredient such Portland cement. The earth mixture is poured into a hydraulic press machine

c. Cement

Before tsunami attack Aceh, cement demands were mostly supplied by PT SAI (Semen Andalas Indonesia). PT SAI was acquired by Lafarge, a French based company. The factory is situated only 25 km (16 miles) from Banda Aceh. It used the local limestone as the main source of producing cement. It also employed 90% of the staff from Aceh. It met the need of cements of approximately 200,000 people in Banda Aceh even for 44,000.000 people over Sumatra Island. However PT Semen Andalas Indonesia (SAI) was then unproductive due to the earthquake and tsunami devastated in 2004. As the cement needs was quite high to get through the post tsunami reconstruction, such demands were then met by importing from Medan. Those were Padang and Cibinong cement. While the cement imported from Lhokseumawe comes from Malaysia in bulk form which was then packed in Semen Andalas (SAI) brand as it was under the same company, Lafarge. Then the long term cement demand has been met by Lafarge by rebuilding PT SAI which was reopened in March 2011 (Tumatar, 2010).

d. Sand

Sand is one of the most important building materials. During post tsunami rehabilitation and reconstruction, sand was majorly mined in Aceh Besar, the nearest district to Banda Aceh. Excessive amounts of sand have been mined causing roads and bridges to be destroyed in the mining area. Even worse that along Krueng Aceh (Aceh river), the main area of mining sand, the well water has run dry due to such irresponsible mining that effects the local residents (Mulieng, 2008).

e. Stones, rocks and infill soil

As with sand, stones or rocks are either excavated from mountains or rivers; and infill soil from hills was also obtained from Aceh Besar. Pekan Biluy, a place in Aceh Besar has been continuously exploited leading to damage the hills and rivers. Even some of the hills have been flat due to continuous dredging every day. Water that flows into the field also turns yellows because it mixes with dust and mud (Mulieng, 2010).

f. Glass and metal

Glass and metal are not locally produced. Pre-tsunami the materials were imported from outside such as Java. During the post tsunami reconstruction the materials are also obtained from outside Aceh with high prices due to the huge demand.

Apart from glass and metals, almost all of the building materials used in rebuilding Aceh were obtained from Aceh. Significant issues arose due to such high demand of the building materials in catching up with the reconstruction were drastically high price of the materials (Nazara et. al., 2007); and damaged environment due to the excessive excavation (Bapedalda NAD & GTZ-SLGSR, 2006). In 2010, five years after tsunami attack where all of the constructions of houses for the tsunami victims were finalized, nature was still being exploited irresponsibly. The local residents have complained about the damaged environment. However the excavators have denied doing anything wrong and claimed to have the legal permission to carry it out (Mulieng, 2008).

It is unlikely that there has been much action regarding the provision of sustainable building materials, since there have been many complaints and destroyed environments are still clearly seen. Timber is a different case. Even though that there were still small actions of illegal logging, as it has become scarce there have been alternative proposed as explained in table 5.3.

### 5.3.7 Workmanship

13% of building workers are said to be from inside Aceh, 31.7% are from outside Aceh, 2.9% are from both Aceh and outside Aceh and the remaining 52.45% of the house holders do not know where the builders are from. Involving the local people in building the post tsunami housing actually is a positive contribution to the area, for example minimising the workmanship costs since no need to travel them long distances; and giving a sense of belonging for people who participate in building their own house. Nevertheless if there is no specific construction training provided, it will result in poor quality of workmanship and therefore poor quality of house construction (da Silva, 2010).

## 5.4 Lighting

53.4% of the householders specify that their houses are strongly daylit during the day while the remaining percentages are specified as also good even though sometimes the artificial lighting is needed. Most of the houses are lit by fluorescent artificial light with the mean hours of lighting use in each room is about 5.5 hours per day with a range of 1.75-13 hours. 98.1% of the householders are satisfied with the day lighting provisions. The remaining 1.9% who is unsatisfied is mostly caused by the inappropriate opening provisions. More explanation about the day lighting is described in chapter 6.8.

## 5.5 Noise

Noise in post tsunami houses has been surveyed using questionnaire only due to unavailability of measuring equipment. Most of the householders do not consider noise as a significant problem either inside or outside their houses. Up to 70.2% occupants specify their houses as quiet and even very quiet, 27.8% slightly noisy and just noisy; and only 1.9% regard them as too noisy (figure 5.5). The most common noise noticed by the householders having the noise problem is coming from outside such as vehicles, children's voices playing outside and construction works, while the inside noise is mostly caused by appliances such as TV switched on at high volume.

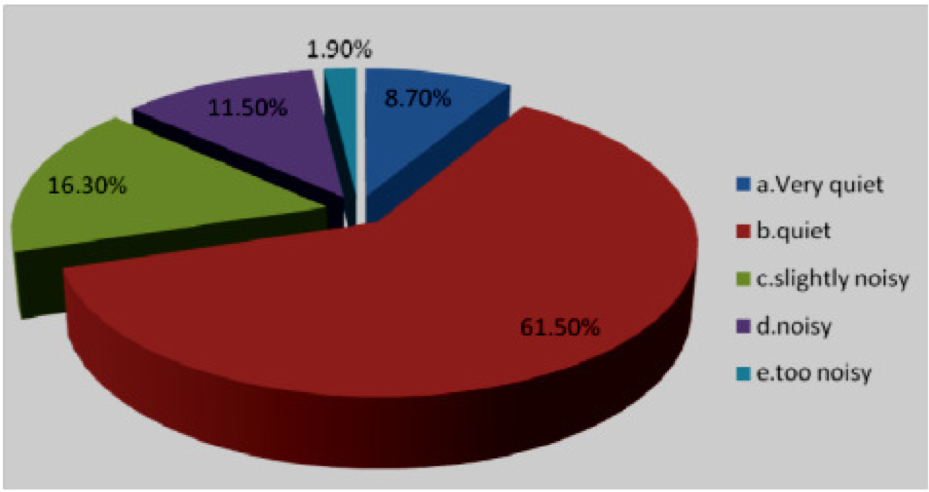



Figure 5.5 Noise descriptions

## 5.6 Environmental/ Surrounding Assessment

### 5.6.1 Flooding

Aceh actually has a low and coastal topography that is susceptible to flooding. However, from 208 houses surveyed which spread over the tsunami affected sub districts, flooding were not regarded as a major problem, since only 12% of the householders complain about the flooding in their living area, which is mostly caused by rain, blocked drainage, the low house position, and the overload of water from the sea during rainy days. The flooding affected areas are located about 0.8km from the water line (mostly sea).

### 5.6.2 Vegetations and outside surface covers

Vegetations as a shading tool in cooling the environment, especially in tropics, were also observed during the survey. 50% of the houses are not shaded by any vegetation or planting at all. 12% are only planted with the small vegetation such as flowers; 31.7% are shaded in small numbers with 50cm-3m high of planting; 3.8% are shaded by high trees and only 2.4% are fully shaded perfectly with a combination of plantations.

The outside surfaces are mostly uncovered ground (54.8%); 15.4% are covered by the hard surface such as concrete, cemented floor and paving block; 29.9% are covered with a mixture of materials such as gravels, stones, and grass; while only 8.7% are greened with grass surface.

## 5.7 Water and waste treatment

### 5.7.1 Water needs

Clean water used for daily activities is mostly obtained from ground wells and the water centrally distributed by the local government. The quality of centrally distributed water is good, yet highly recommended to be boiled before consumed. Meanwhile the quality of the water from ground well is uncertain. The health department reported that 88.56% of the ground water in Aceh is infected by E-coli, which can cause diarrhoea (Haba, 2008). In addition several householders described their ground well water as smelly, coloured and tasty and impossible to consume. Direct drinking water which is sold almost everywhere is now commonly purchased by householders either tsunami victims or not. The quality of such water is actually still questionable since the price is various that may determine its quality, but it is beyond this study.

Recycling water such as the reuse of grey water is not a common habit in Aceh even in Indonesia in general, which can be due to the lack information and knowledge of how to do it and an understanding of its importance. Nevertheless, harvesting the rain is observed to have been used currently in a manual and traditional way. Even though there only 22.6% of the householders harvested the rain, it is a good beginning in understanding how to deal with it. Most of the rain harvested is for watering plants, washing cars/ vehicles, and even some  for cooking and drinking which is boiled first.

### 5.7.2 Waste treatment

Waste treatment in this case includes water waste and solid waste. Water waste is related to sanitation dealing with grey and black water. Pre-tsunami, the sanitation standards in Aceh were poor in general. The population primarily defecated outside the habitat area such as in paddy fields, rivers and beaches (Kumar, 2007; GTZ and UNICEF (2007). In reconstruction phase where thousands of people were waiting for houses, the focus was more on rapid construction. There was insignificant thought given to sanitation by only providing simple and temporary solutions. As early as 2005, the government of Indonesia advised all housing construction to bring the responsibilities of providing sustainable sanitary facilities with the form of leach field as the minimum acceptable standard (Badan Standarisasi Nasional 2000).

In this study where the survey was carried out in 2009, from the 208 houses observed 95.2% of black water and sludge is collected in a septic tank which is commonly built in a shallow concrete well. These wells are roughly made in 3-5 rings deep. The black water and the sludge are collected inside the well until it is full; afterward the sludge car removes all of the full sludge to the final process. Only very small numbers of septic tanks are made from much more sufficient material such as biofil, the Fibre Reinforced Plastic (FRP) septic tanks, plastic tanks which are water tight and therefore able to significantly reduce the contamination of groundwater. This observation shows that the black water was still mostly treated conventionally by using the septic tank instead of the minimum recommended standard that is leach field system.

Grey water should actually be treated integrated with the black water system as shown in figure 5.6 and 5.7. Figure 5.6 and 5.7 are vegetated leachfield that is an open system in which primary-treated wastewater is evenly distributed through a horizontal, perforated pipe laid in a gravel bed. The gravel bed is covered with sand then densely planted with fast-growing plants, which ‘harvest’ nutrients, the main pollutants found in ground and surface waters. Horizontal flows in the leachfield distribute wastewater over a large area for treatment by roots and microbes in the gravel. This system is quite good in preventing water pollution and the reproduction of mosquitoes and flies (GTZ and UNICEF, 2007).


Figure 5.6 Environmentally-friendly simple sanitation system (Source: UN Habitat, 2011)

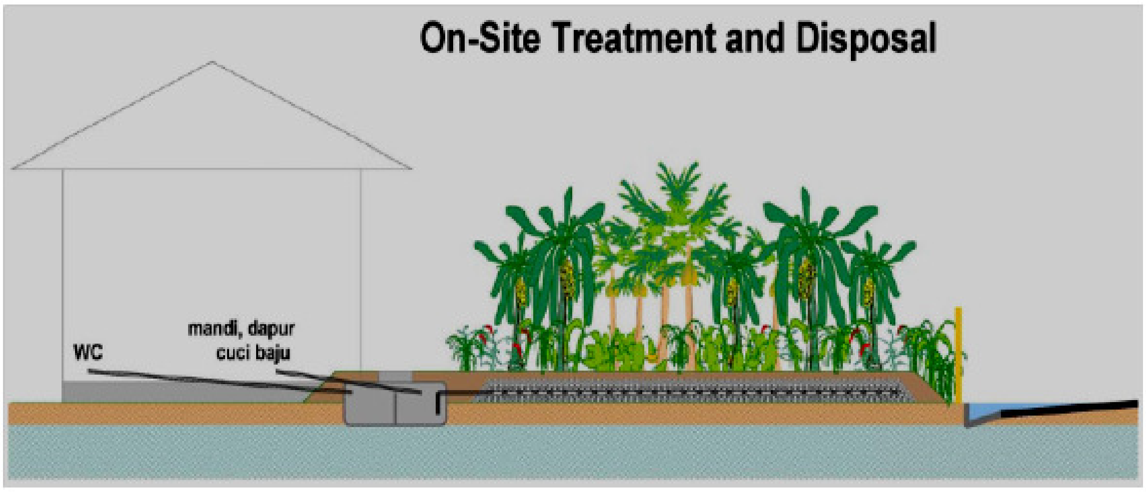



Figure 5.7 Concrete septic tank + above ground vegetated leachfield (Source: GTZ and UNICEF (2007).

Nevertheless, in this study we found that there are only about 66.8% of houses completed with trenches or drainages to transfer the grey water (without the initial recycle process) and the unused rain water to the final water collection in this case such as streams or rivers. In that number, about 19.7% of the householders complain that the trenches are blocked, unused and dirty. The remaining 33.2% of houses are without trenches letting the water be stagnant surrounding their houses.

About 35.1% of house holders have their daily sewage collected regularly either by the local government, local community or the house donor in this case such as Buddha Tzu Chi. While the remaining 64.9% process their daily sewage in their own way such as burning, composting, burying and unpleasantly by throwing the rubbish to anywhere such as river or the unused land which may be the result of having no rubbish bin nor sewage collection place nor even knowledge of how to deal with it.

There are actually some environmental, societal and institutional challenges in installing sustainable sanitation system in Aceh as the place with low and coastal topography, such as follows (Kumar, 2008):

- High groundwater tables in resettlement communities which is up to 0.4m to 1m.
- The flat coastal topography providing few opportunities for gravity flows in drainage channels.
- Various soil types and conditions that can cause for instance water logging for many days after rains in low-lying areas.
- Fewer concerns on sanitation than for other services such as water and power
- Lack of knowledge so the communities do not recognise the benefits of sanitation
- There is not a clear 'institutional home' for sanitation, which leads to difficulties with policy development and effective implementation
- 'The focus of reconstruction has been uneven, with too much importance on large infrastructure development, and much less emphasis on the needs of households'.

Those challenges may also be the reasons to have such conventional waste treatment as previously mentioned.

### 5.8 Access to local facilities (between 500 m- 1 km from the neighbourhood)

The accesses to local public facilities such as to health centers, schools, prayer buildings, markets, public toilets, public transports and public transport are described in figure 5.8.

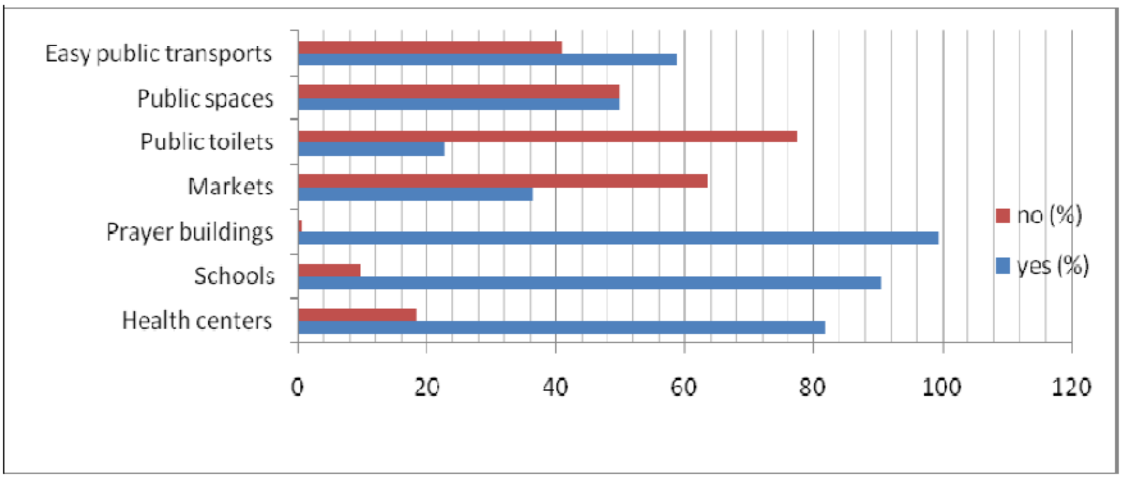



Figure 5.8 Access to local facilities

Almost one hundred percent of areas of the post tsunami housing are provided with the Islamic prayer building (mosques), this is due to the Islamic religious characteristic of Acehnese people that puts the mosque as the most priority one. Schools and health centers seem to be prioritized as well, while public toilets are not likely to be prioritized, as only 22.6% of the areas are provided with public toilets. It is very important for the market to be located nearby; nevertheless only 36.5% of the householders can reach the market in 500m-1 km distance. The reason for this might be due to the large markets that are located just 15 minutes away by motorbike which may mean that not many people want to carry out their business in such nearby distance. Public transport is still out of reach for about 40.9% of the house holders which actually needs to be addressed by the government.

### 5.9 SBS

Sick Building Syndromes (SBS) was not found as a problem in this survey (figure 5.9). Initially, the writer and the surveyors suspected that there must be SBS occurring in some post tsunami houses, since several houses were built from asbestos material. Nevertheless, more than 90% of householders are healthy. Fewer than 10 % of householders complain about their health with regard to headache, eye irritation, nose irritation, throat irritation, dry cough, dry skin, itchy skin, dizziness, difficult in concentration, fatigue, sensitive odors, asthma and depression.

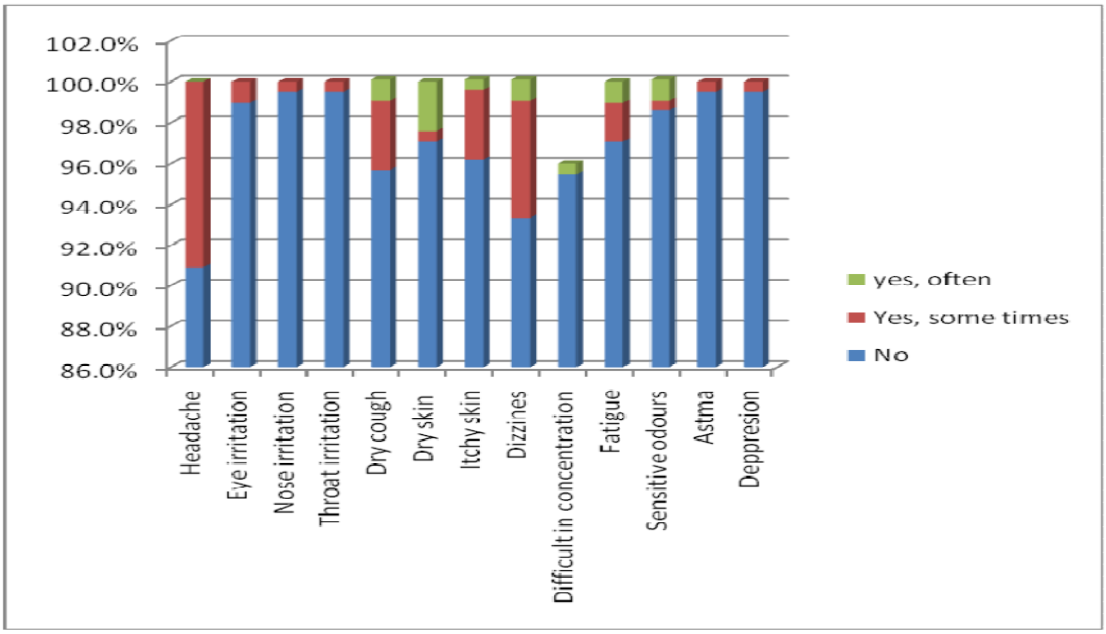



Figure 5.9 Unsignificant number of people suffering sick building syndroms

Most of the householders have lived in those houses for not more than four years. Some illnesses such as asbestos symptoms do not usually show up for many years, sometimes it takes up to 30 years to develop (Thompson Solicitor, 2010). Hence, four years of occupancy may not be sufficient time to survey the sick building syndroms.

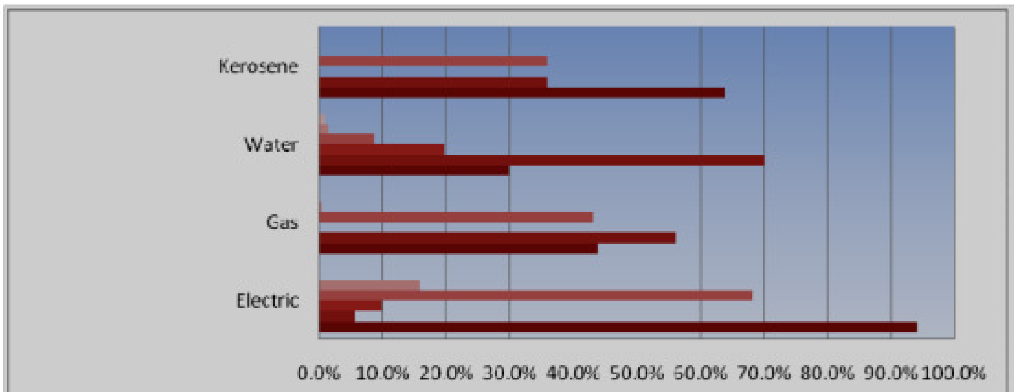
### 5.10 Energy assessment

Figure 5.10 shows that 94.2% of the houses surveyed in this study have electricity supplied centrally by the local government. Yet only about 84.2 % pay the monthly electric bill. The remaining 10% do not pay the bill at all. The most amount of the monthly electric bill paid by the occupants is less than IDR 100,000.00 (GBP 8.00) with average electricity usage less than 253 kWh per month. During the survey, some house holders mentioned the reasons why they do not pay the electric bill, such as follows:

1. The illegal electric supply carried out by the house holder through the main electric supply box nearby their house. This is actually very dangerous either for the house supplied through that way or the surrounding neighborhood.

2. No electric meter provided in their house, and

3. They have never paid the electric bill since the occupancy time




| | Electric | Gas | Water | Kerosene |
|---|---|---|---|---|
| monthly bill: > Rp 200,000.00 | 0.0% | 0.0% | 1.0% | 0.0% |
| monthly bill: Rp 100,000.00-Rp 200,000.00 | 15.9% | 0.5% | 1.4% | 0.0% |
| monthly bill: <Rp100,000.00 | 68.3% | 43.3% | 8.7% | 36.1% |
| Not pay | 10.0% | 0.0% | 19.7% | 0.0% |
| Not use | 5.8% | 56.2% | 70.2% | 36.1% |
| Use | 94.2% | 43.8% | 29.8% | 63.9% |

Figure 5.10 Average monthly bills of post tsunami house occupants

About 43.8% of the house holders use gas for cooking. 63.8% use kerosene for cooking and some other activities, such as for lighting once the electrical supply is off during the night. Gas and kerosene are purchased individually by the householders. There is no central supply for both gas and kerosene managed by the government directly to each house; hence from the figure above we see that all of the householders using these both powers pay the bill otherwise they cannot use it.

There is water supplied centrally by the local government to post tsunami houses. But only 29.8% of the surveyed houses are provided with that water. And yet only about 11% of those numbers pay the monthly bill which is mostly less than IDR 100,000.00 for monthly bill. The monthly average use of water is less than 20m$^3$. The reasons of the remaining 19.7% of households that did not pay the water bill are almost jus the same as the reason not to pay the electric bill such as follows:

1. No water meter box provided
2. The water has been just installed so they have never paid yet

### 5.11 Satisfaction

UN Habitat through its monitoring carried out together with Syiah Kuala University assessed the satisfaction of tsunami survivors with the houses donated on several issues such as:

- Did the house donors work properly?
- Did they fulfill their promises?
- Were the occupants satisfied with the works of any one in charged with the house building? Etc.

After 18 months occupation the survey was conducted by UN Habitat monitoring team, the overall satisfaction rate was 6 in the range 0 to10. They concluded that 18 months was quite a short time for the people to decide and express their satisfaction due to a huge amount of insecurity regarding how to fulfill their daily needs, how to keep their children earning education and so on. Therefore score of 6 just may simply express their unclear satisfaction (UN Habitat, 2006).

In this study, through the survey conducted in 2009 we asked the house holders about their overall satisfaction of their houses in terms discussed in this study such as house design, day lighting provision, thermal comfort, environmental issues and energy assessment.

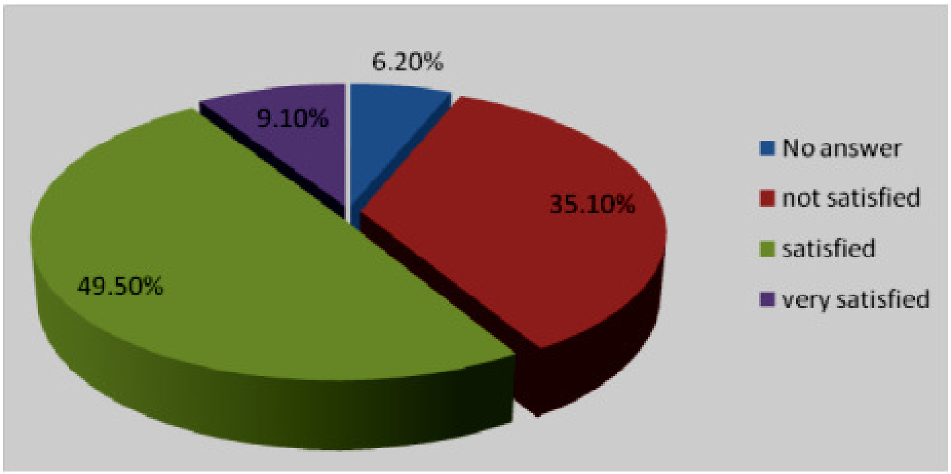



Figure 5.11 Overall satisfactions on post tsunami housings

From figure 5.11 we see that more than 50% of the householders are satisfied with their houses. Only 35.10% that are not satisfied mention that they are not happy mostly with construction quality, the thermal comfort inside their house and also the bad building materials. Nevertheless, it is actually quite difficult to find out the real answer for this question, since many house holders are very grateful for the houses. For them it is much more comfortable to live in those houses then live in barracks (temporary dwelling) for instance. This study also shows that four years after the tsunami attack does not seem to be a sufficient time for the long assessment of sustainability issues. More studies need to be carried out in the next few years to understand how people deal with donated houses and how the living environments will affect them (Sari et. al., 2010).

## 5.12 Conclusion

Table 5.3 summarizes the aspects covered in questionnaires which are previously explained in the above sub chapters.

Table 5.3 Summary of questionnaire results

| **Aspect** | **Survey result** | **Assessment/ advice** |
|---|---|---|
| **House descriptions** | Post Tsunami houses were designed by donors following the house type mostly preferred by tsunami victims (heavy weight-grounded floor house) | Houses are advised to follow the character of Acehnese vernacular houses (Building code, 2006). Yet, House donors are more advised to consider the community preferable house types yet still keep being on the safe building track (Boen, 2007) |
| | Each post tsunami house is occupied by 1 to 5 occupants per $36m^2$ of house area | Meet minimum standard size (Building code, 2006). Yet separate rooms are advised for different activities (a big house with one room for each activity) (Larasati, 2006) |
| | Front sides of the houses where the more openings are located orient variously following the existing road | Building openings in tropics are advised to be located facing north and south to avoid direct sun radiation |
| **House materials/ Embodied energy** | Roof is predominantly sloping zinc roof which is left unpainted<br>• Walls are mostly made from brick work<br>• Floors are mostly cement plaster<br>• Windows are single glass framed in wood | Advised to use eternit roof (clay tile roof) (Building code, 2006).<br>Meet minimum standard size (Building code, 2006). Yet organic material than can be obtained locally such as woven bamboo, coconut fiber and wood from replanted forest are more advised to be used (Larasati, 2006) |
| | Using exported timber, and local timber yet in limited small | • Increasing price due to high demands<br>• Illegal logging of timber may occur due |

| | | |
|---|---|---|
| | quantity | to huge demand of timber |
| | Using local sand, soil and stones | Excessive excavation of those materials resulting damaged environment |
| | Employing local and outside labour yet still within Indonesia | Minimising the workmanship cost, Nevertheless if there is no specific construction training provided, it will result in poor quality of workmanship and therefore poor quality of house construction (da Silva, 2010). |
| **Lighting** | 53.4% of the householders specify that their houses are strongly day lit during the day | No efforts to use solar-powered lights in the night time |
| | Using conventional light bulbs and energy-saving light bulbs, | |
| **Noise** | 70.2% occupants specify their houses as quiet | No specific efforts against noise pollution, since no such problem has arisen at the moment |
| **Surrounding assessment** | 12% of the householders complain about the flooding | Only small numbers look to have problems with flooding, yet the houses should be designed to prevent the flooding |
| | 3.8% are shaded by the high trees | More advised to the householders to green their surroundings |
| **Water and waste treatment** | Difficult access to drinking water: Only small number of houses is provided with water centrally installed by government. Many people consume drinking water from the ground well with uncertain quality. Some other prefers to buy the water. | Having own well is quite good to self supply the need of water, nevertheless no purification of water quality carried out |
| | Most of households proceed the daily sewage in the traditional way such as burning, composting, burying and unpleasantly by throwing the rubbish to any where such as river or the unused land which may be the result of having no rubbish bin nor sewage collection place nor even knowledge in how to deal with it. | Far from sustainable manner in dealing with rubbish such re-cycle, re-use etc. |
| **Access to local facilities** | Primary public facilities and services are available, yet public | There should be more concerns of the availability of public transport |

| | | |
|---|---|---|
| | transportations still difficult to catch | |
| **SBS** | More than 90% regard that there are no such symptoms of SBS | Four years of occupancy may not be sufficient time to survey the sick building syndromes. |
| **Energy Assessment** | Some of the houses are supplied with conventional energy sources such as electricity and water, but some others not | far from sustainable manner in dealing with energy sources such as solar energy for generating electricity etc |
| | Not all of houses provided with the power pay the bill | |
| | The most amount of the monthly electric bill paid by the occupants is less than IDR 100,000.00 (GBP 8.00) with average electricity usage less than 253 kWh per capita. | This figure is relatively low when compared to the average use of the whole area in Indonesia in general which was 352.59kWh per capita in year 2008 (Wikipedia, 2011). Nevertheless, it is necessary for Acehnese people to be more sustainable in consuming their electricity, since the energy use keeps rising as the number of population rises every year. |
| **Satisfaction** | More than 50% of the householders are satisfied with their houses | Four years after the tsunami attack does not seem to be a sufficient time for the long assessment of sustainability issue |

The overall results show that the post tsunami housing is still built conventionally. It seems that there has been no integration between the housing construction and the house maintenance especially for supporting the occupation stage such as power and water supply; treating the waste etc. Lack of knowledge about sustainable living in the community worsens the situation to keep the life wheel on the conventional track. The excessive uses of local building materials during the reconstruction process have not been followed up in a responsible manner causing damage to the environment.

# CHAPTER 6 – INDOOR THERMAL PERFORMANCE IN POST TSUNAMI HOUSING BASED ON FIELD MEASUREMENTS

## 6.1 Introduction

In order to obtain an understanding of indoor thermal performance of the post tsunami houses, the field measurement of the inside air temperature, relative humidity and air speed was carried out. As previously explained in chapter 4, due to the limited measuring tools, the thermal parameters of 188 houses representing varied house donors were recorded only over one hour during the day. Another 20 houses which were selected to represent the 188 houses were measured over two days.

On the first line, this chapter presents the indoor thermal performance of the houses based on the house providers. The measurements were carried out only over one hour during the day. This will be followed by the analysis of thermal mean vote; the most way people take to cool them; and the quality of the indoor air. Further the indoor thermal performance of the twenty houses measured over the longer period is presented. As the comparison, the inside air temperature and relative humidity in Acehnese traditional house, and in unaffected existing houses are also presented.

Indoor thermal performance in the post tsunami housing was assessed through the comparison between the inside and the outside data of air temperature and relative humidity. The inside air movement was also measured in order to understand their relationship. This performance was further compared with the comfort temperatures using the neutral temperature equations applied in the tropics, proposed by Humpreys, Auliciems, Grifith, Nicol, and Karyono.  In this study, the inside air temperatures of the housing are compared with the neutral temperature studied by Karyono in Jakarta that is $23.9^0$C-$29.7^0$C in the range of $-1<PMV<1$. This value is taken instead of the value found by Feriadi conducting his work in NV housing in Yogyakarta because Jakarta climate looks more similar to Aceh climate. In spite of the case conducted in AC and NV office which makes it also applicable to be compared with NV house, the neutral temperature of karyono's work was used to compare the NV building and house in Jakarta as well (Karyono, 2010).

## 6.2 Indoor Thermal performance of Post Tsunami Houses Based on the House Provider

In this study, both the inside and outside thermal parameters were recorded simultaneously in 188 houses over one hour from May 11th-July 19th 2009. The 188 houses are categorized Heavy weight house, light weight house, and semi permanent house. The light weight house is characterized by walls constructed of GRC board, and kalsiboard (5mm-10mm thick). The semi permanent house is constructed from plastered brick wall (150mm thick, 1 m high above the floor) and wood plank (10mm thick, 2 m high above the one meter brick wall), while the wall of the heavy weight house is constructed of clay brick and concrete brick with a thickness of 150 mm.

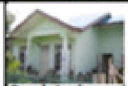
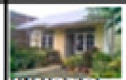
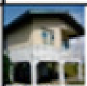
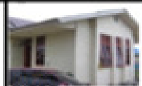
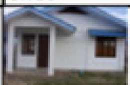
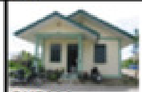
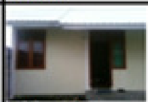
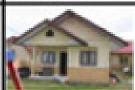
Table 6.1. Comfort Survey Indicator

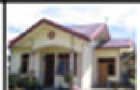
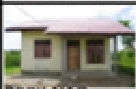
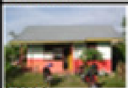
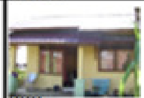
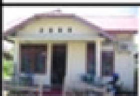
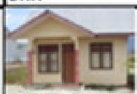
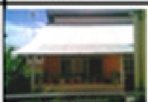
| | |
|---|---|
| Clothing level (clo) | 0.35 |
| Metabolic rate (met) | 1.2 (dwelling case ) |
| Respondent gender (%) | |
| Male | 25 |
| Female | 75 |
| Respondent age (%) | |
| < 25 | 0 |
| 25-35 | 45 |
| 36-45 | 35 |

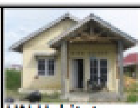
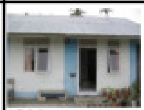
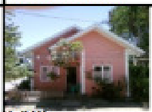
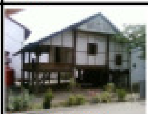
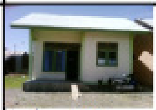
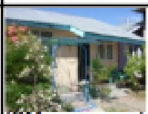
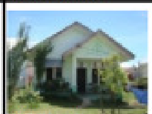
The participants in this survey were mainly women (75%) because the fieldwork was carried out during the day when men were mostly out at work. Since this study analyzed the general performance of comfort throughout the day, the metabolic rate and the clothing level calculated are also the average obtained from the households daily activities which are 0.35 clo and 1.2 met respectively (table 6.1).

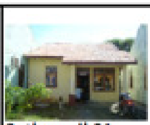
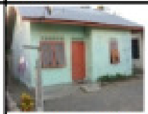
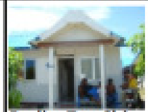
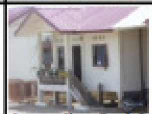
Before going further with indoor thermal assessment in the house type based on the building material weight, the indoor thermal performance of the 188 measured post tsunami houses were assessed based on the house design and facade performance. The assessment was carried out using the average of one hour measured temperature data during the day. The measuring times were between 0900-1200 hrs, 1200-1500 hrs and 1500-1800 hrs. The 188 post tsunami houses are represented in 40 different house forms as shown in table 6.2. The table shows the rank of the measured houses based on the house design that was most effective in reducing the outside air temperature during the day.

Table 6.2 Indoor thermal performance of post tsunami houses based on house performance designed by varied house providers

| No | House Provider | House type | Sub District | Tai (LR) | Tai (BR) | Rh (LR) | Rh (BR) | Tao | Rho | Air speed | tdif (tai LR-tao) | tdif (tai LR-tn*) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 |  Bank Indonesia | Heavy weight | Syiah Kuala | 33.1 | 33.0 | 58.5 | 59.4 | 33.3 | 47.6 | 3.3 | -0.1 | 3.4 |
| 2 |  World Vison | Heavy weight | Meuraksa | 32.7 | 32.6 | 61.4 | 61.6 | 32.7 | 50.2 | 4.2 | 0.0 | 3.0 |
| 3 |  YBI | semi permanent | Meuraksa | 33.7 | 34.1 | 58.2 | 57.9 | 33.6 | 45.1 | 3.5 | 0.1 | 4.0 |
| 4 |  Saudi Arabia | Heavy weight | KutaRaja | 29.7 | 29.8 | 74.6 | 74.4 | 29.5 | 62.8 | 5.0 | 0.2 | 0.0 |
| 5 |  UN Habitat | Heavy weight | KutaRaja | 30.7 | 30.7 | 71.6 | 71.5 | 30.4 | 61.3 | 5.3 | 0.3 | 1.0 |
| 6 |  UPLINK | semi permanent | Meuraksa | 31.7 | 31.7 | 67.1 | 67.0 | 31.4 | 54.8 | 3.8 | 0.3 | 2.0 |
| 7 |  P2KP | Heavy weight | Syiah Kuala | 34.9 | 35.0 | 59.6 | 62.0 | 34.5 | 43.5 | 2.6 | 0.4 | 5.2 |
| 8 |  GITEC | Heavy weight | Jaya Baru | 33.1 | 33.0 | 64.1 | 63.9 | 32.7 | 54.8 | 3.7 | 0.4 | 3.4 |
| 9 |  CRS | Heavy weight | Syiah Kuala | 32.9 | 39.5 | 58.9 | 66.2 | 32.3 | 55.7 | 3.1 | 0.6 | 3.2 |
| 10 |  OXFAM | Heavy weight | Meuraksa | 33.3 | 33.3 | 62.9 | 62.9 | 32.5 | 51.6 | 2.2 | 0.9 | 3.6 |
| 11 |  Satker BRR | Heavy weight | Kuta Alam | 34.0 | 34.0 | 60.5 | 60.6 | 33.0 | 50.2 | 2.8 | 1.0 | 4.3 |
| 12 |  PMI | Heavy weight | Meuraksa | 34.2 | 38.3 | 54.7 | 58.8 | 33.1 | 49.1 | 3.6 | 1.1 | 4.5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 |  Uni Emirat Arab | Heavy weight | Meuraksa | 32.6 | 32.5 | 60.3 | 60.6 | 31.3 | 54.4 | 1.6 | 1.2 | 2.9 |
| 14 |  UPLINK | Heavy weight | Meuraksa | 33.3 | 39.5 | 48.9 | 65.0 | 32.1 | 55.0 | 2.7 | 1.2 | 3.6 |
| 15 |  Habitat for Humanity | Heavy weight | Jaya Baru | 34.0 | 33.8 | 67.8 | 59.8 | 32.6 | 50.3 | 4.2 | 1.4 | 4.3 |
| 16 |  UPLINK | Heavy weight | Meuraksa | 32.9 | 40.7 | 57.5 | 65.3 | 31.4 | 60.1 | 2.3 | 1.5 | 3.2 |
| 17 |  Adecco | Heavy weight | Meuraksa | 34.6 | 35.0 | 58.3 | 57.1 | 33.1 | 48.3 | 2.1 | 1.5 | 4.9 |
| 18 |  Turkish Red Crescent | Heavy weight | Jaya Baru | 34.9 | 34.8 | 52.7 | 53.9 | 33.4 | 44.9 | 4.1 | 1.6 | 5.2 |
| 19 |  BPPK NAD | Heavy weight | Meuraksa | 33.0 | 39.6 | 60.5 | 66.8 | 31.5 | 59.4 | 1.9 | 1.6 | 3.3 |
| 20 |  GITEC | semi permanent | Jaya Baru | 33.3 | 33.3 | 63.4 | 63.1 | 31.7 | 55.5 | 3.0 | 1.6 | 3.6 |
| 21 |  BRR | Heavy weight | Jaya Baru | 36.5 | 36.4 | 47.3 | 47.9 | 34.8 | 38.0 | 3.0 | 1.8 | 6.8 |
| 22 |  BRR | Heavy weight | Jaya Baru | 34.3 | 42.4 | 51.5 | 61.2 | 32.4 | 51.7 | 4.1 | 1.9 | 4.6 |
| 23 |  CARITAS | Heavy weight | Meuraksa | 34.5 | 57.4 | 34.7 | 57.8 | 32.6 | 48.6 | 3.1 | 1.9 | 4.8 |
| 24 |  World Vision | Heavy weight | KutaRaja | 35.2 | 35.1 | 54.6 | 57.3 | 33.3 | 45.5 | 4.6 | 1.9 | 5.5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 |  UN Habitat | Heavy weight | Meuraksa | 34.5 | 34.5 | 55.8 | 55.3 | 32.6 | 52.1 | 3.5 | 2.0 | 4.8 |
| 26 |  CRS | Heavy weight | Syiah Kuala | 34.2 | 34.2 | 67.6 | 68.2 | 32.2 | 57.2 | 3.2 | 2.1 | 4.5 |
| 27 |  IOM | Light weight | Syiah Kuala | 34.2 | 47.1 | 47.6 | 62.6 | 32.1 | 55.1 | 3.8 | 2.1 | 4.5 |
| 28 |  Oemar Bakrie | Light weight | Kuta alam | 33.7 | 33.2 | 66.1 | 65.4 | 31.5 | 57.4 | 2.6 | 2.3 | 4.0 |
| 29 |  CARE | Heavy weight | Kuta Alam | 35.7 | 35.7 | 58.5 | 58.9 | 33.5 | 48.1 | 3.9 | 2.3 | 6.0 |
| 30 |  Muslim Aid | Light weight | Kuta Raja | 35.3 | 35.2 | 52.5 | 52.7 | 33.0 | 45.4 | 2.9 | 2.3 | 5.6 |
| 31 |  Satker ADB | Heavy weight | Kuta Alam | 34.8 | 34.8 | 63.0 | 63.1 | 32.5 | 53.7 | 3.5 | 2.3 | 5.1 |
| 32 |  IOM- permanent | Heavy weight | Jaya Baru | 34.5 | 34.6 | 59.4 | 59.1 | 32.2 | 52.8 | 2.2 | 2.3 | 4.8 |
| 33 |  Aceh Relief | Heavy weight | Kuta Alam | 33.6 | 33.5 | 68.1 | 68.3 | 31.1 | 59.1 | 2.1 | 2.4 | 3.9 |
| 34 |  Katahati | Heavy weight | Kuta Alam | 34.7 | 34.6 | 62.8 | 63.1 | 31.9 | 55.6 | 4.4 | 2.8 | 5.0 |
| 35 |  PKPU | Heavy weight | Kuta Alam | 34.1 | 34.1 | 63.0 | 62.9 | 31.3 | 58.1 | 3.0 | 2.9 | 4.4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 |  Satker wil 01 | Heavy weight | Kuta Raja | 35.0 | 34.7 | 60.2 | 60.1 | 31.4 | 56.5 | 3.2 | 3.6 | 5.3 |
| 37 |  IMM | Heavy weight | Syiah Kuala | 35.8 | 35.6 | 54.8 | 55.5 | 31.8 | 54.0 | 3.6 | 4.0 | 6.1 |
| 38 |  Yayasan Peduli Bangsa | Heavy weight | Jaya Baru | 37.9 | 38.8 | 49.1 | 48.0 | 33.7 | 42.1 | 4.1 | 4.2 | 8.2 |
| 39 |  Budha Tzu-Chi | Light weight | Lueng Bata | 35.8 | 35.7 | 61.4 | 61.5 | 31.5 | 62.3 | 2.1 | 4.3 | 6.1 |
| 40 |  Australian Red Cross | Heavy weight | Syiah Kuala | 34.2 | 34.4 | 59.7 | 59.8 | 28.4 | 74.4 | 2.1 | 5.7 | 4.5 |

*tn: the highest neutral temperature range of Indonesia (29.7C)(Karyono, 2000)

In this study mainly heavy weight houses were assessed since such house types are the most common house type provided by the donors. It is also the house type preferred by the beneficiaries. Light weight and semi permanent were not the preferable ones among the tsunami victims which were therefore only donated by 4 and 3 NGO's respectively.

The heavy weight house is expected to be more durable and strong by most people. However with regard to thermal performance, table 6.2 shows that if the heavy weight house is not treated to be the house adapting the hot humid climate, it gives severe high inside air temperatures (shown by the higher inside air temperature in the house donated by Australian Red Cross which is 5.7$^0$C higher than the outside air temperature). Only the house provided by Bank Indonesia has an inside air temperature slightly lower than the outside value, yet it is still higher by 3.4$^0$C than the neutral temperature of Indonesia (29.7$^0$C).

Among those house performances, the houses provided by Saudi Arabia (house 4) and the Turkish Red Crescent (house 18) were regarded as attractive by the house beneficiaries. However, such houses have high inside air temperatures which are by 0.2$^0$C and 1.6$^0$C respectively higher than the outside air temperature during the day.

During the measurement day, table 6.3 shows that the outside air temperature and air speed at 1200-1500 hrs are higher than the value at 0900-1200 hrs and 1500-1800 hrs. Responding to this, the heavy weight and the semi permanent house tend to show the same trend by having the highest inside air temperature at 1200-1500 hrs and respectively followed by the value at 1500-1800 hrs and 0900-1200 hrs. Conversely, corresponding with the light building materials, the light weight house raises the inside air temperature earlier by having the highest value at 0900-1200 hrs and respectively followed by the value at 1200-1500 hrs and 1500-1800 hrs. During the day, the light weight is shown to have the highest inside air temperature which is 3.9$^0$C higher than the outside air temperature.

Table 6.3 Indoor thermal performance of post tsunami houses based on house types during the day.

| weight | | Air temperature ($^0$C) | | | Relative humidity (%) | | | Outside air speed (m/s) |
|---|---|---|---|---|---|---|---|---|
| | | Tai | tao | tdif | Rhi | Rho | Rhdif | |
| heavy weight9-12 | Mean | 33.5 | 31.5 | 2.1 | 61.8 | 57.0 | 4.8 | 2.1 |
| | Std. Deviation | 1.4 | 1.7 | 1.6 | 4.9 | 8.6 | 7.4 | 1.3 |
| heavyweight12-15 | Mean | 34.3 | 32.6 | 1.7 | 60.0 | 51.5 | 8.4 | 3.6 |
| | Std. Deviation | 1.7 | 1.6 | 1.8 | 6.8 | 9.0 | 6.7 | 1.4 |
| heavyweight15-18 | Mean | 33.9 | 32.3 | 2.2 | 61.9 | 52.9 | 9.9 | 3.8 |
| | Std. Deviation | 1.8 | 1.5 | 3.8 | 7.0 | 8.2 | 11.3 | 1.1 |
| lightweight9-12 | Mean | 35.3 | 31.5 | 3.9 | 59.4 | 57.3 | 2.1 | 1.7 |
| | Std. Deviation | 2.3 | 0.6 | 1.8 | 6.1 | 0.4 | 5.8 | 0.6 |
| lightweight12-15 | Mean | 35.1 | 32.9 | 2.2 | 58.5 | 49.0 | 9.5 | 3.1 |
| | Std. Deviation | 1.4 | 1.1 | 1.5 | 7.6 | 8.6 | 6.7 | 1.3 |
| lightweight15-18 | Mean | 34.6 | 31.4 | 3.2 | 61.3 | 59.2 | 2.1 | 2.5 |
| | Std. Deviation | 1.3 | 1.4 | 1.7 | 8.4 | 9.6 | 7.0 | 0.8 |
| half_permanent9-12 | Mean | 33.3 | 33.4 | -0.1 | 58.8 | 48.7 | 10.1 | 2.7 |
| | Std. Deviation | 1.1 | 0.5 | 0.7 | 0.9 | 3.8 | 3.9 | 2.7 |
| half permanent 12-15 | Mean | 34.9 | 34.0 | 0.9 | 56.9 | 38.5 | 18.4 | 5.4 |
| | Std. Deviation | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| half permanent15-18 | Mean | 32.0 | 31.8 | 0.3 | 65.5 | 52.5 | 13.0 | 3.9 |
| | Std. Deviation | 2.3 | 1.2 | 1.5 | 7.9 | 6.7 | 4.1 | 0.7 |

Notes:

- 9-12: measuring time at 0900-1200 hours
- 12-15: measuring time at 1200-1500 hours
- 15-18: measuring time at 1500-1800 hours

As the outside air temperature is high at 1200-1500 hrs, the inside relative humidity of the three house types works conversely to be the lowest at that time. The inside relative humidity is shown to be high at 1500-1800 hrs. It follows the trend line of hourly outside relative humidity data which continues to increase while the day turns to be evening and night. The average of inside RH value during the day is ranged between 56.9%-65.5%. It is just close to the upper range of comfort humidity level (70%) where people will feel uncomfortably wet above it.

### 6.3 Mean Thermal Sensation

During the survey, the householders' thermal sensations were collected in the questionnaire. By using the ASHRAE scale (-3: cold; -2: cool; -1: slightly cool; 0: neutral; 1: slightly warm; 2: warm; 3: hot) the householders voted their general sensation during morning, afternoon, evening; and during the dry and the rainy seasons throughout the year shown in the figures below:

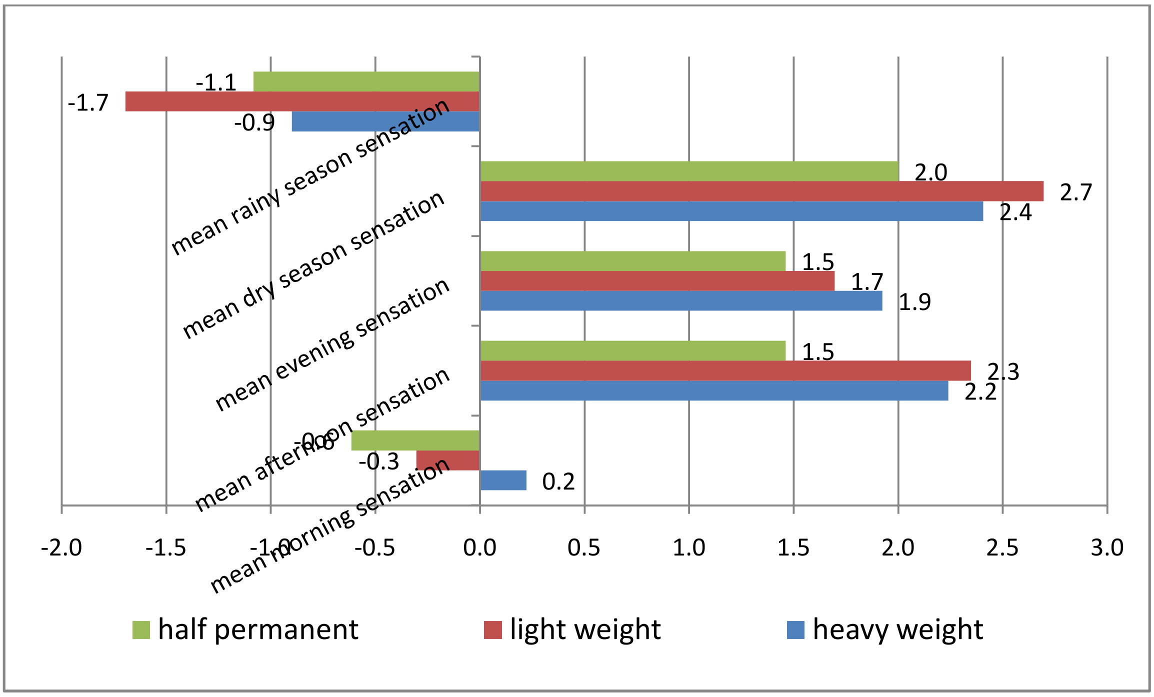



Figure 6.1 Mean thermal sensation value voted by householders in 188 post tsunami houses

Figure 6.1 shows that during the morning most of the householders are shown to be slightly comfortable with a score of -0.6 and 0.2. During the afternoon the light weight house suffers the highest vote, about 2.3 (warm-hot), while in the evening the heavy weight house radiates its day heat into the house making it the house suffering the highest thermal sensation among those types, about 1.9 (warm). Nevertheless, during the evening all types are regarded as more than slightly warm (>1). The outside air temperature during the evening is actually lower than during the day, nevertheless people regard their houses as warm; this may be caused by the daytime heat radiated into the house due to the time lag caused by the building envelope material; also because of the lack of air circulation inside the house. During the evening people normally close their windows to prevent the mosquitoes entering their houses, which may result in indoor thermal discomfort. In the dry season, all of the householders regard their houses as warm-hot while in the rainy season they are slightly cool.

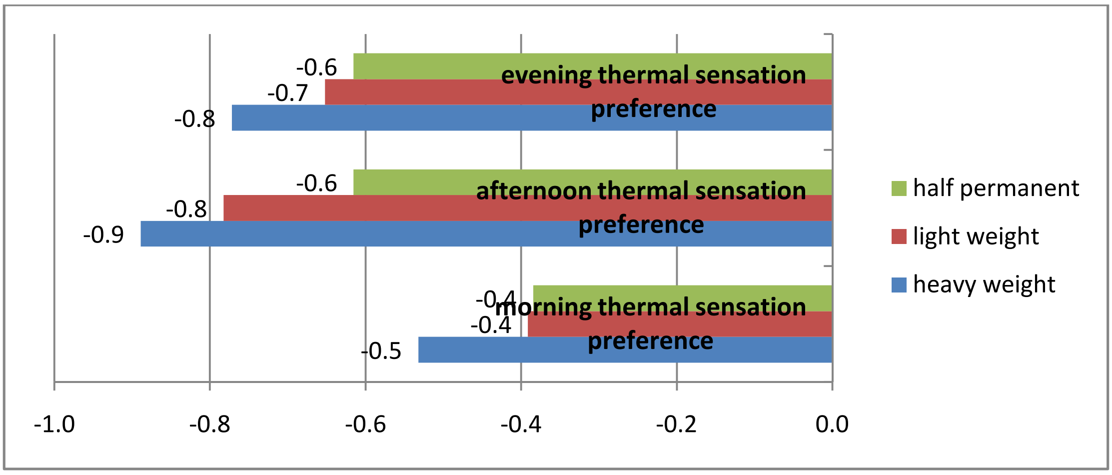



Figure 6.2 Thermal preference in post tsunami houses throughout the year

Figure 6.2 shows that even though people feel slightly comfortable during morning, they still prefer to have the cooler thermal sensation as well as during the afternoon and evening shown by the thermal sensation preference less than zero (based on the preference range -1: cooler; 0: no change; 1: warmer). In dealing with indoor thermal discomfort, most of the householders choose open doors as the first action to try to get cool, followed by turning on electric fans, opening the window, taking off clothing layers, switching on AC and using hand fans respectively. Most of the householders move the window curtain to let the day light come through, yet opening windows seems to be the third priority which may be due to the window style used, which is awning with a very limited opening angle that may contribute less air movement. This makes the use of electric fans preferable to opening the window since it gives significant cooling (figure 6.3).

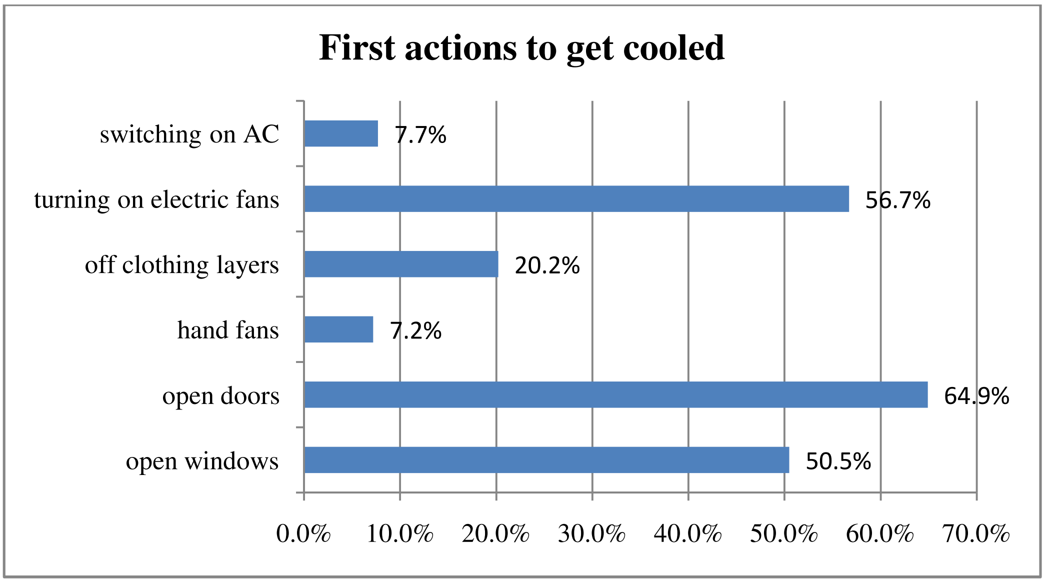



Figure 6.3 Percentage of house holders' actions to get cooled

**6.4 Inside Air Movement**

During the survey most of the house holders did not open the windows. Windows seem to be only used to let the day lighting come through. There may be a number of reasons for this, such as security. Due to this, it is quite difficult to see the relationship between the window types and the air movement rates. However, most of the householders specify the general air movement rate in the house (window types: casement, awning) as gentle, while the house with louver window is mostly regarded as moderate.

Table 6.4 Inside air velocity of post tsunami houses differentiated in varied window types

| Window types | Mean air velocity (m/s) | Number of cases | Std. Deviation |
|---|---|---|---|
| Awning | 0.16 | 12 | 0.07 |
| Awning and louver | 0.19 | 2 | 0.00 |
| Casement | 0.17 | 4 | 0.05 |
| Louver | 0.16 | 2 | 0.02 |

As stated previously that it is quite difficult to see the relationship between the window type and the air movement rate; it is shown in table 6.4 above that there are no significant differences in air velocity among the several types of windows in the ten measured house types. The mean air movement for all of those window types is quite light which is about 0.16 m/s whereas the outside air speed during the day is about 3.2 m/s (table 6.3).

### 6.5 Inside Air Quality

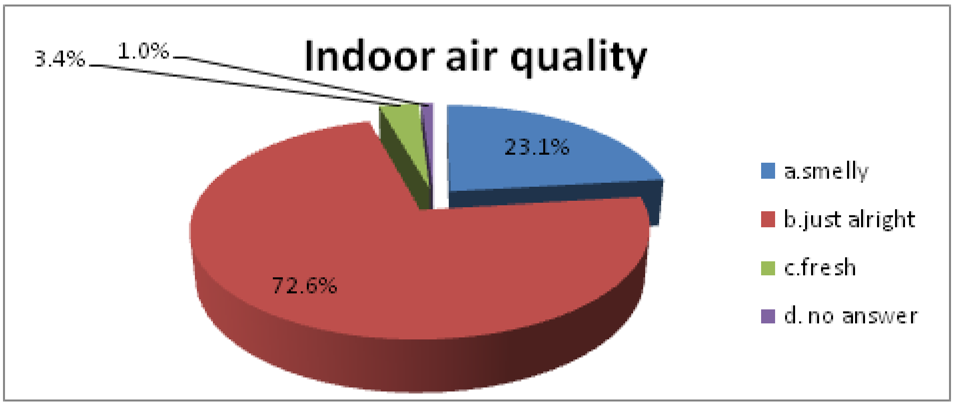



Figure 6.4 Indoor air quality of the measured houses

72.6% specified the indoor air quality as 'just alright and 3.4% as fresh. 23.1% of the householders regarded their indoor house quality as smelly, specifying that the source of the smell is mostly from outside such as animal sludge/ waste, unmaintained drainage/ trench, and garbage. Another 1.4% of them recognise that the smell is from kitchens and toilets (figure 6.4).

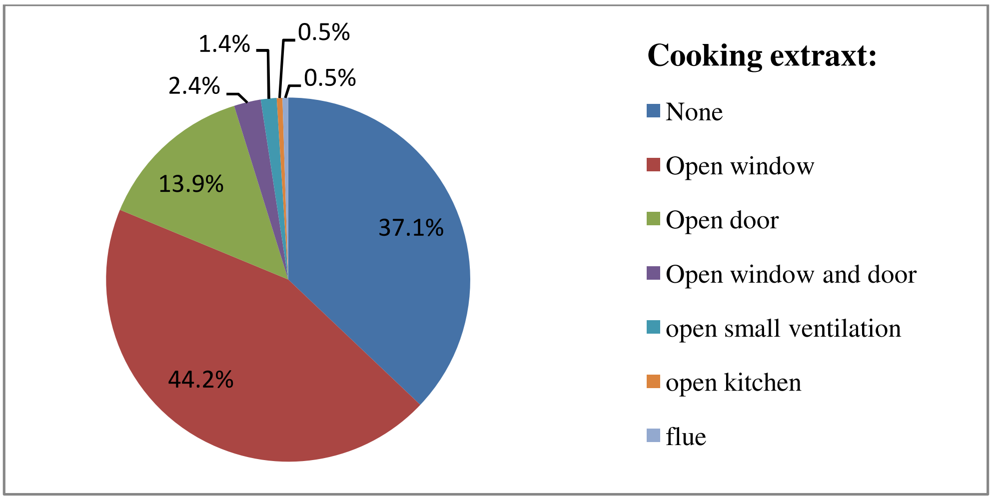



Figure 6.5 Cooking extract used in post tsunami houses

With regard to inside smell source that may come from the kitchen as well, we observed that 37.1 % of the houses do not have any cooking extracts, 62.9% of the house holders using the cooking extracts such as opening windows (44.2%) and 13.9 % open doors (figure 6.5).

### 6.6 $CO_2$ contamination performance

The air quality is also influenced by the amount of $CO_2$ contamination in the air. During the survey, $CO_2$ level was measured over one hour during the day in twenty houses representing the ten types of post tsunami houses.

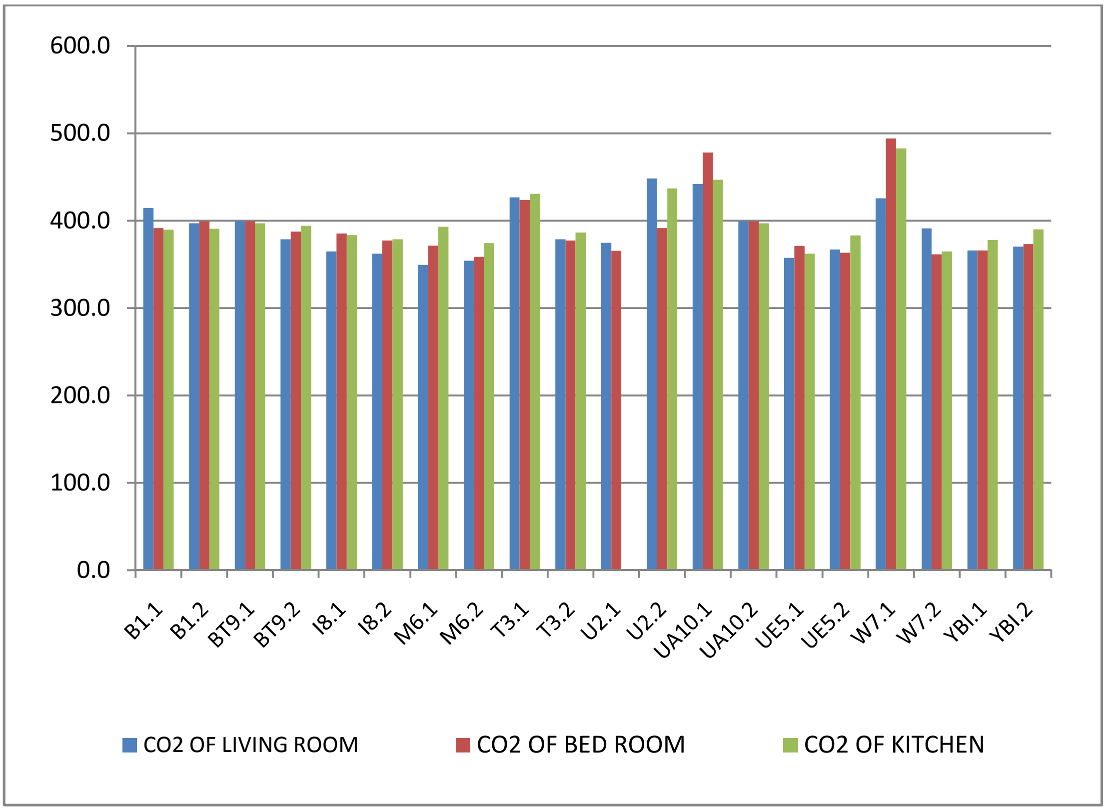



Figure 6.6 $CO_2$ level (ppm) of Post Tsunami Houses

The graph above shows that most of rooms in each house types have quite a low level of $CO_2$, that is mostly less than 400 ppm (mean $CO_2$ level: 393.15 ppm). Based on Wisconsin Department of Health Services (2008), the $CO_2$ level in the air and potential health problems are:

- 250 - 350 ppm – background (normal) outdoor air level
- 350- 1,000 ppm - typical level found in occupied spaces with good air exchange.
- 1,000 – 2,000 ppm - level associated with complaints of drowsiness and poor air.

- 2,000 – 5,000 ppm – level associated with headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
- >5,000 ppm – Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma and even death.

Thus, the 393 ppm of $CO_2$ level in post tsunami housings is an acceptable level and no householders gave complaints regarding this issue during the survey.

### 6.7 Longer Thermal Assessments on 20 houses

In this study, the environmental performances of the ten types of houses (figure 6.7) are indicated by the following parameters; air temperature, relative humidity, air velocity and surface temperature. The inside and outside air temperature and relative humidity were recorded simultaneously over two days for each sample of each type. Meanwhile the inside air velocity and surface temperature were recorded simultaneously only for limited periods, namely between 10.00-11.00 and 15.00-16.00 in each house, due to the lack of availability of instruments and surveyors.

Those ten types are figured as follows:

| | |
|---|---|
| 1. Code: B1  | Type : One storey house<br>Floor area : $36m^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : clay bricks plastered with cement<br>Floor : ceramic tile<br>Ceiling: ply wood<br>Openings (window):single glass with wood frame<br>Roof : sloping metal roof |
| 2. Code: U2  | Type : floor raised house<br>Floor area : $36m^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : clay bricks plastered with cement and wood plank (half permanent)<br>Floor : wood plank<br>Ceiling: ply wood<br>Openings (window):single glass with wood frame<br>Roof : sloping zinc roof |

| | |
|---|---|
| 3. Code: T3<br> | Type : One storey house<br>Floor area : 48 m$^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : clay bricks plastered with cement<br>Floor : ceramic tile<br>Ceiling: ply wood<br>Openings (window):single glass with wood frame<br>Roof : sloping metal roof |
| 4. Code: Y4<br> | Type : One storey house<br>Floor area : 36 m$^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : clay bricks plastered with cement and wood plank (half permanent)<br>Floor : cement<br>Ceiling: ply wood<br>Openings (window):single glass with wood frame<br>Roof : sloping zinc roof |
| 5. Code: UE5<br> | Type : One storey house<br>Floor area : 48 m$^2$<br>Height of ceiling: 4 m<br><br><u>Building material</u>:<br>Wall : clay bricks plastered with cement<br>Floor : ceramic tile<br>Ceiling: ply wood<br>Openings (window):single glass with wood frame<br>Roof : sloping metal roof |
| 6. Code: M6<br> | Type : floor raised house<br>Floor area : 40 m$^2$<br>Height of ceiling: 1-3 m<br><br><u>Building material</u>:<br>Wall : GRC board framed with coconut tree column<br>Floor : wood plank<br>Ceiling: ply wood insulated with aluminium foil beneath the zinc sheet<br>Openings (window):single glass with wood frame<br>Roof : sloping zinc roof |
| 7. Code: W7<br> | Type : One storey house<br>Floor area : 36-45m$^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : concrete bricks plastered with cement<br>Floor : cement<br>Ceiling: none- directly covered by roof sheet<br>Openings (window):single glass with wood frame<br>Roof : sloping zinc roof |

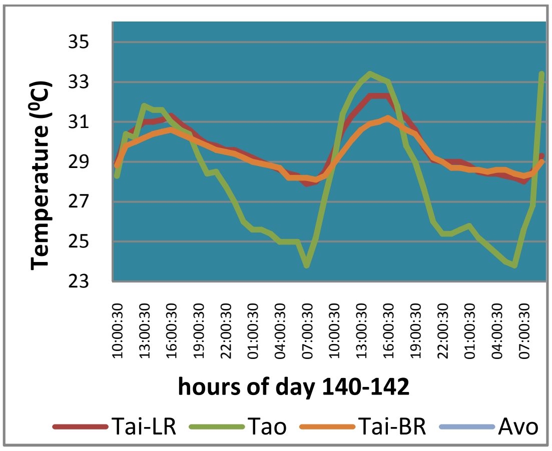
| | |
|---|---|
| 8. Code: I8<br> | Type : One storey house<br>Floor area : 36 $m^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : kalsiboard<br>Floor : cement<br>Ceiling: none- directly covered by roof sheet<br>Openings (window):single glass with wood frame<br>Roof : sloping zinc roof |
| 9. Code: UA9<br> | Type : Two-storey house<br>Floor area : 36 $m^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : clay bricks plastered with cement<br>Floor : ceramic tile<br>Ceiling: ply wood<br>Openings (window):single glass with wood frame<br>Roof : sloping metal roof |
| 10. BT10<br> | Type : One storey house<br>Floor area : 36 $m^2$<br>Height of ceiling: 3 m<br><br><u>Building material</u>:<br>Wall : GRC board<br>Floor : ceramic tile<br>Ceiling: GRC board<br>Openings (window):single glass with wood frame<br>Roof : sloping aluminum roof |

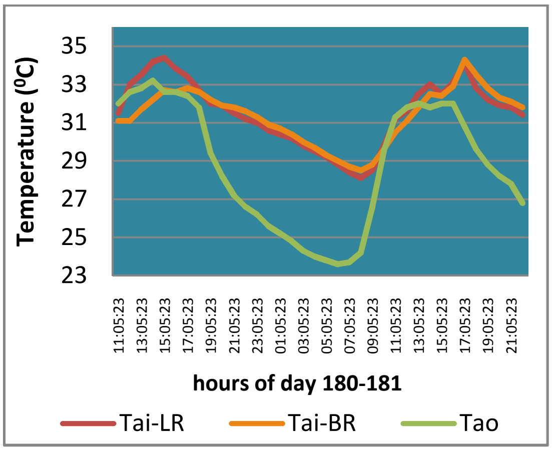
Figure 6.7. The House Types surveyed over two days

The graphs in figure 6.8 present the swing of inside air temperature of bed room (tai-BR) and living room (tai-LR); and outside air temperatures (tao). There is not so much difference between the inside and the outside data of each house in the same type. The little difference between them is mostly due to the position of the house toward the sun, the surrounding influences such as shadows from trees, and the density of the environment in terms of the closeness and number of surrounding houses.

The last graph of BT10 shows the results over a longer measurement period. This was done to give a general impression of the temperature swings for several days. It performs an almost identical swing throughout each day. The lower peak outside temperature on the $12^{th}$ July was believed to be caused by a rain shower of about 0.5 mm.

1. B1 (House donor: BRR)



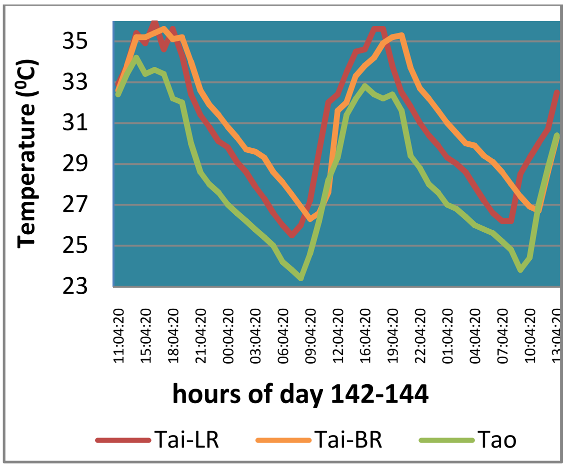



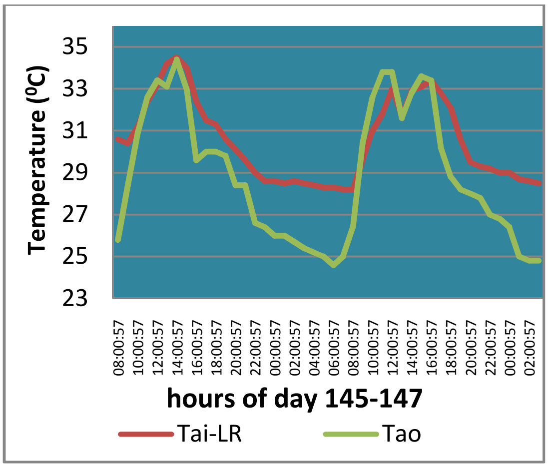

B1.a B1.b

Comments for house B1.a and B1.b:

Both of these houses were built in the same style by the same donor, i.e. grounded heavy weight house. However B1.a has a wider floor area which is more than 36m$^2$, moreover the owner of this house built more rooms to the house making the house area wider up to 60m$^2$, while house B1.b is quite small, less than 36m$^2$. This may be the reason for the lower inside air temperature in B1.a than in B1.b.

2. U2 (House donor: UPLINK)



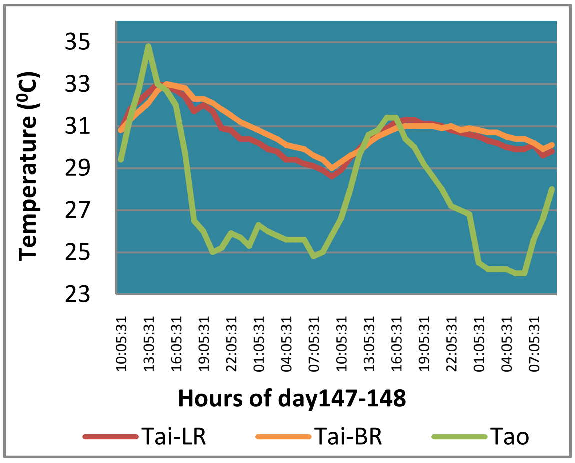




U2.a U2.b

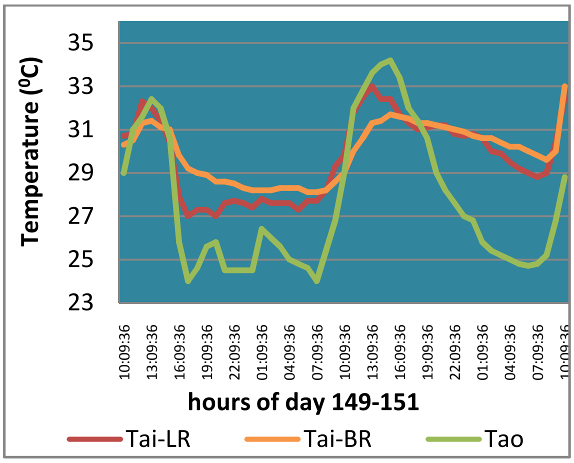
Comments for house U2.a and U2.b:

These houses were built in the same type by UPLIK, i.e. raised floor-semi permanent house. The difference occurred in the way the occupants treat their houses. The occupant in U2.a did not use any curtains to the window and let the ground floor free. While the occupant in U2.b used curtains to shade all windows and used the ground floor as a family room. This may be the reason to have the inside air temperature in U2.b slightly lower than the value in U2.a. The heat of sun radiation and air convection transmitted to U2.b was obstructed by the curtain and the family room under the first floor therefore reduced the inside air temperature.

3. T3 (House donor: Turkish Red Crescent)




T3.a

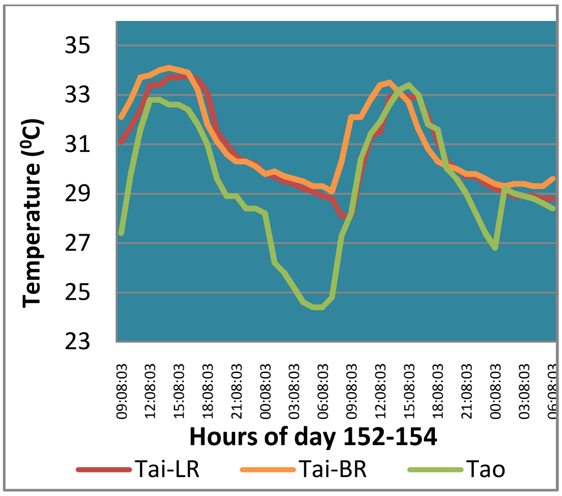



T3.b

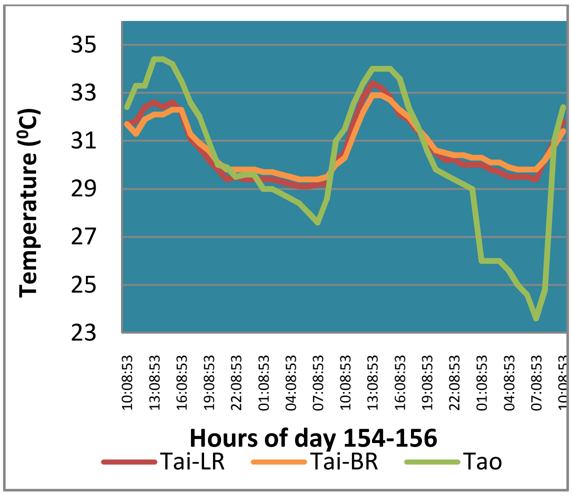
Comments for house T3.a and T3.b:

There are no significant differences in the inside air temperature in these two houses. The houses built by Turkey Red Crescent are grounded floor-heavy weight houses. It may confirm that the occupants treat the houses in similar way.

4. Y4 (House donor: Yayasan Berkati Indonesia- YBI)




Y4.a

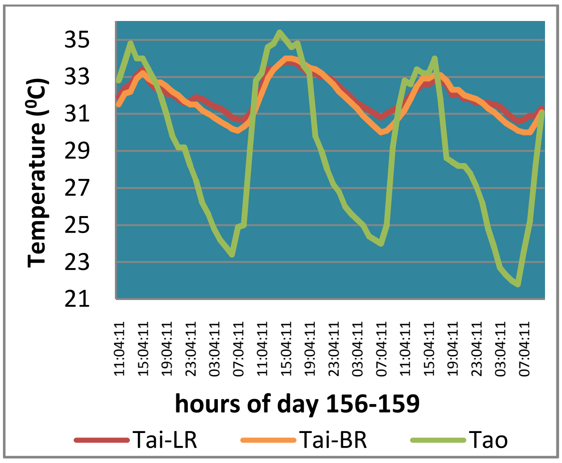



Y4.b

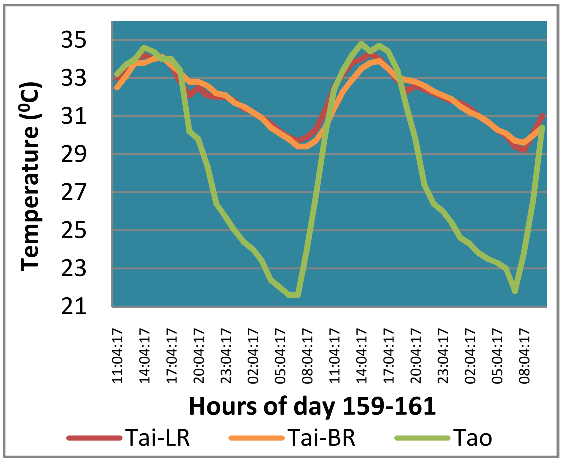
Comments for house Y4.a and Y4.b:

These are semi permanent houses built by YBI. Apart from having similar house type, house Y4.b had more rooms added by the owner. The great number of rooms and therefore wider the floor area may reduce the inside air temperature in Y4.b.

5. UE5 (House donor: Saudi Arabia)




UE5.a

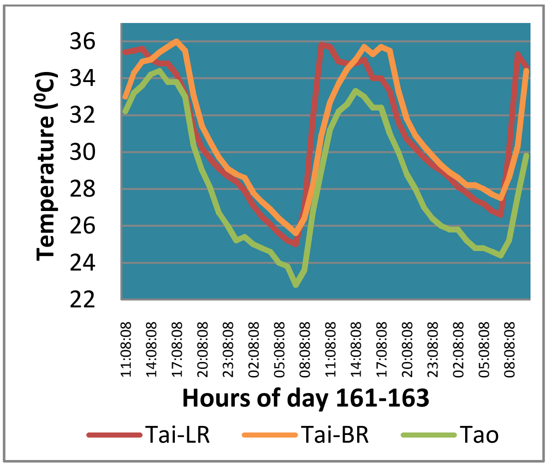



UE5.b

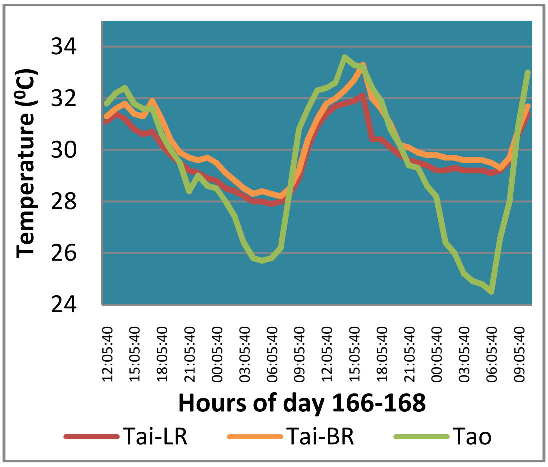
Comments for house UE5.a and UE5.b:

House UE5.a and UE5.b were built of a similar type. However UE5.a has 3 bedrooms, whereas UE5.b has only 2 bedrooms. The great number of rooms and therefore wider house area may help to reduce the inside air temperature in UE5.a

6. M6 (House donor: Muslim Aid)




M6.a

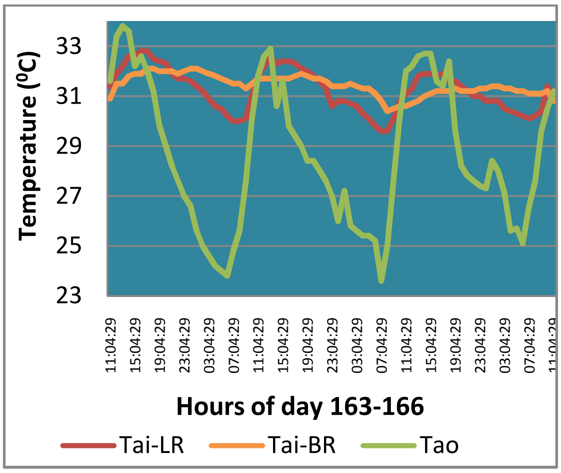



M6.b

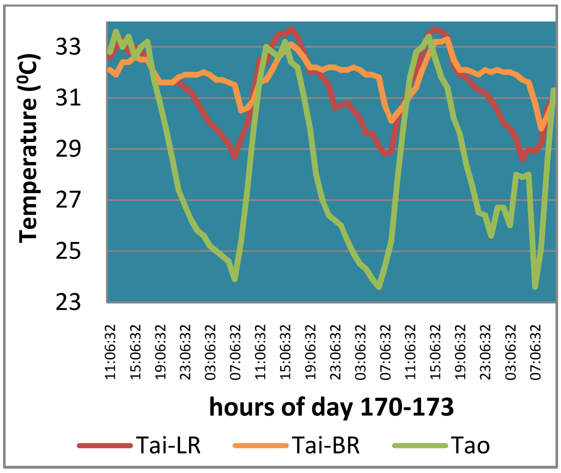
Comments for house M6.a and M6.b:

These houses were built in similar way by Muslim aid, i.e. raised floor-light weight house. However the occupant of M6.b apart from adding plywood sheet under the roof, also closed some windows during the day. This may be the reason for the lower inside air temperature compared with house M6.a.

7. W7 (House donor: World Vision)



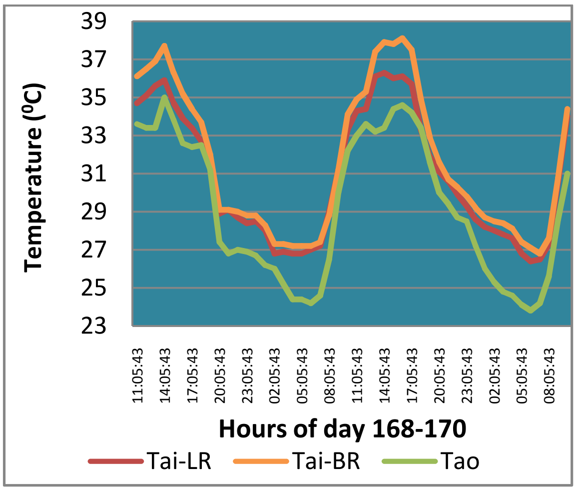

W7.a



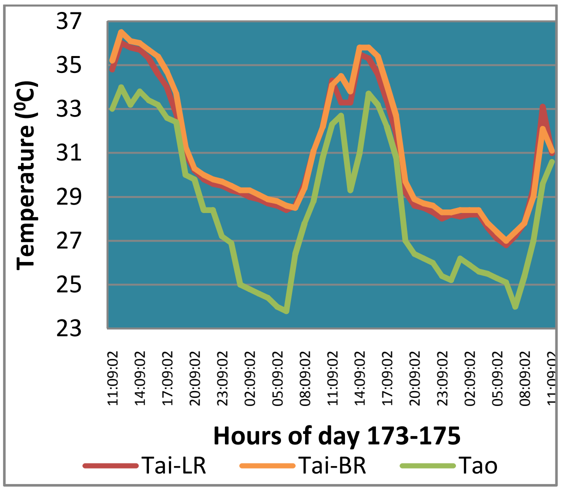

W7.b

| |
|---|
| Comments for house W7.a and W7.b:<br><br>The inside air temperatures in the both houses look quite similar. The semi detached house built in heavy weight construction by World Vision looks to have very high inside air temperature during the absence of sun due to the time lag of thermal mass. |

8. I8 (House donor: IOM)



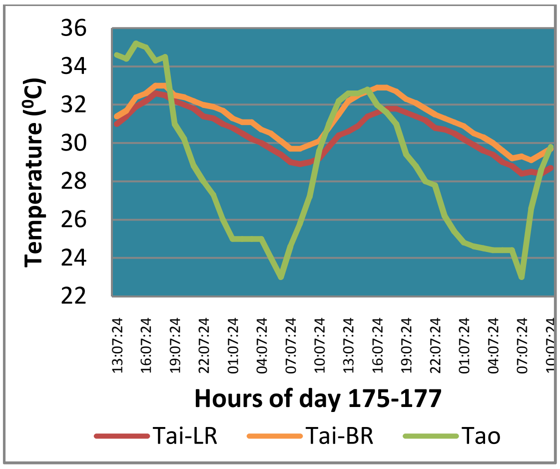

I8.a

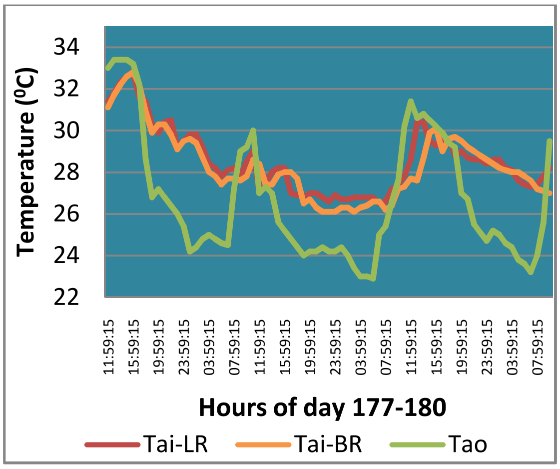



I8.b

| |
|---|
| Comments for house I8.a and I8.b:<br><br>These light weight houses show the typical trend line of high inside air temperature during the day. There is no difference between the two figures that can show that the occupants of the houses may treat the houses on the same way. |

9. UA9 (House fonor: UN habitat/ ADB)



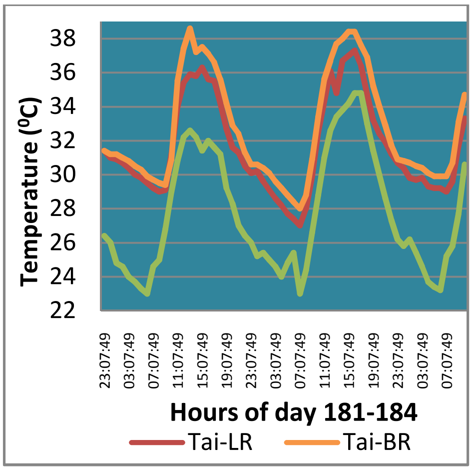



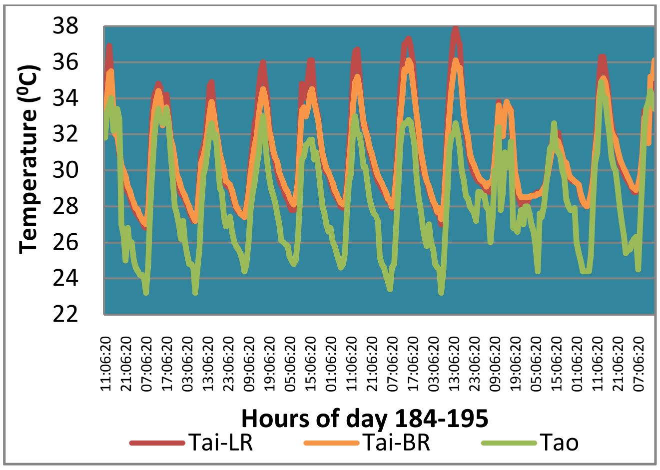

UA9.a UA9.b

Comments for house UA9.a and UA9.b:

House UA9.a was built by UN Habitat while UA9.b was built by ADB (Asian Development Bank). These houses have the same type, i.e. two storey house built in heavy weight construction. In general there is no significant difference of inside air temperature in the both houses.

10. BT10 (House donor: Budha Tzu Chi)




BT10.a BT10.b

Comments for house BT10.a and BT10.b:

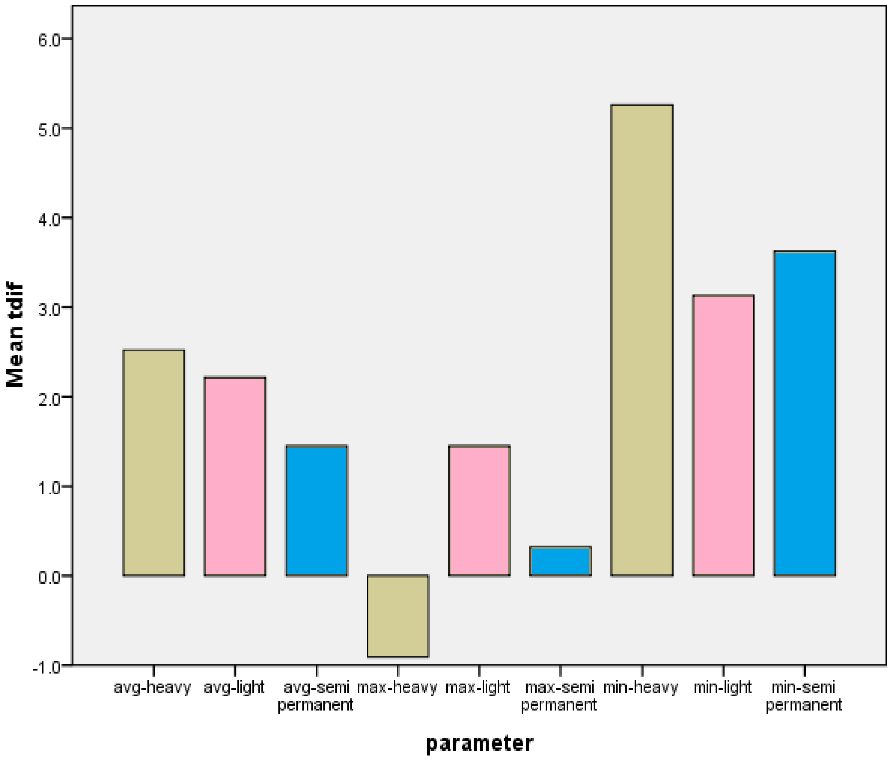
These two houses were built by Buddha Tzu Chi in light weight construction. In general there is no significant difference of inside air temperature in the both houses.

Figure 6.8 Inside and outside temperatures of the ten house types (the reference numbers refer to the house types illustrated in figure 1)

Figure 6.8 shows that the heavy weight house such as B1, T3, UE5, W7, and UA9 tend to have the slightly lower peak inside air temperature during the day and conversely higher than the outside air temperature when the sun goes down. In contrast, light weight houses such as M6, I8 and BT10 have an extremely high inside air temperature which is up by $5^0$C higher than the outside air temperature. Semi permanent houses such as U2 and Y4 also tend to have higher inside air temperature, however the value is slightly lower compared with the value in the light weight house. The two house types (light weight and semi permanent) have lower inside air temperature than the value in heavy weight house when the sun is down. The mean thermal data collected from 20 houses as the representative of the ten types of houses is shown in appendix B.

During this survey, rain only occurred on the measurement day of house T3, UA9 and BT10 with the precipitation of 13 mm, 21.9 mm, and 0.5mm respectively. This is shown in appendix B by the high mean outside relative humidity of 97.5%, 97% and 93% respectively. Nevertheless, this precipitation amount does not influence either the mean inside temperatures or the mean inside relative humidity, which are almost identical with others.

### 6.7.1 Temperature Difference




Notes:

T diff =Tai-tao

Positif bar = tai > tao

Negative bar = tai < tao

Figure 6.9. Overall performance of temperature difference in the three type houses

Figure 6.9 shows the overall performance of the three type houses in reducing the outside temperature. On average, the semi permanent house has the lowest temperature difference meaning, that that the inside air temperature is close to the outside value. In contrast the heavy weight has the highest minimum temperature difference meaning that the inside air temperature when the sun is down is high, which is up to $5^0$C higher than the outside value. However the maximum value is negative meaning that the inside air temperature is by nearly $1^0$C lower than the outside value as shown in figure 6.9.

### 6.7.2 Time Lag

Table 6.5 shows the various time lags between the inside and outside air temperature. These occur due to the influence of the house design and materials, greater thermal mass creating greater time lags. Table 6.5 shows that M6, I8 an BT10 which are lightly constructed with calsiboard and GRC board have a mean time lag of 0.5 hour which is shorter than the mean time lag of half permanent houses (U2, Y4) and heavy weight houses (B1, T3, UE5, W7, UA9) which are about 1.5 and 1.9 hours respectively.

Table 6.5 . Mean time lags of house construction

| House weight | Mean time lag (hours) | Std. Deviation |
|---|---|---|
| Light (M6, I8, BT10) | 0.5 | 0.7 |
| Half permanent (U2, Y4) | 1.5 | 1.0 |
| Heavy (B1, T3, UE5, W7, UA9) | 1.9 | 1.1 |

### 6.7.3 Surface Temperatures and Air Velocity

Table 6.6 shows that the internal surface temperatures of all houses are $30.5^0$C-$43.9^0$C, which represent very high temperatures for dwellings. I8 showed the highest ceiling temperature, which is up to $43.8^0$C when the outside temperature is only $33^0$C. However, this result may be expected since the ceiling of this house is actually only one sheet of zinc which also serves as the roof, and is positioned on the top directly toward the sun. The mean ceiling temperatures of the houses using a plywood ceiling covered by a zinc roof such as U2, Y4 and W7 are $36^0$C, $34.6^0$C, $36^0$C respectively. Meanwhile ceiling temperature swings in the house covered by the plywood ceiling and the aluminium roof (B1, T3, UE, UE5) are $37.1^0$C, $34.3^0$C, $39.8^0$C respectively.

Table 6.6 Mean surface temperatures *(Note: See the appendix B for the complete table)*

| House types | Outside Air velocity (m/s) | Mean Air velocity (m/s) | | Tao (°C) | mean surface temperature (°C) | | | | | t dif (K) ( surface temperature-tao) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Living Room | Bed Room | | Wall | Ceiling | Floor | Glass | Door | Wall | Ceiling | Floor | Glass | Door |
| B1 | 2.00 | 0.11 | 0.08 | 31.2 | 31.6 | 37.1 | 31.7 | 34.1 | 32.9 | 0.4 | 5.9 | 0.5 | 2.9 | 1.7 |
| U2 | 2.22 | 0.11 | 0.10 | 31.9 | 34.0 | 36.0 | 32.8 | 34.4 | 33.0 | 2.1 | 4.1 | 0.8 | 2.5 | 1.1 |
| T3 | 2.35 | 0.23 | 0.11 | 30.1 | 31.5 | 34.3 | 31.6 | 34.3 | 32.3 | 1.4 | 4.2 | 1.6 | 4.2 | 2.2 |
| Y4 | 3.72 | 0.21 | 0.11 | 32.3 | 33.2 | 34.6 | 30.9 | 34.4 | 32.6 | 0.9 | 2.3 | -1.4 | 2.1 | 0.4 |
| UE5 | 2.79 | 0.24 | 0.15 | 33.2 | 33.3 | 39.8 | 34.9 | 37.4 | 33.0 | 0.2 | 6.7 | 1.8 | 4.2 | -0.1 |
| M6 | 3.18 | 0.20 | 0.15 | 31.9 | 36.0 | 33.8 | 33.3 | 34.8 | 33.9 | 4.1 | 1.9 | 1.4 | 2.9 | 2.0 |
| W7 | 3.21 | 0.17 | 0.15 | 31.5 | 32.4 | 36.0 | 31.8 | 33.6 | 33.1 | 0.9 | 4.5 | 0.3 | 2.2 | 1.6 |
| I8 | 3.22 | 0.27 | 0.12 | 33.0 | 36.9 | 43.8 | 33.3 | 35.4 | 35.8 | 3.9 | 10.8 | 0.3 | 2.4 | 2.8 |
| UA9 | 2.81 | 0.26 | 0.18 | 30.9 | 31.5 | 32.5 | 31.4 | 32.9 | 32.1 | 0.6 | 1.6 | 0.5 | 2.0 | 1.2 |
| BT10 | 3.35 | 0.23 | 0.06 | 32.6 | 33.4 | 38.6 | 32.5 | 33.8 | 33.4 | 0.8 | 6.0 | -0.1 | 1.2 | 0.8 |

Most of the internal ceiling temperatures are higher than other surface temperatures. However M6.a.b could provide a lower ceiling temperature nearly equal to other surfaces in the house envelope. This may be a result of using aluminium foil heat insulation beneath the zinc roof. UA9 also has the lower internal ceiling surface temperature, since the measured ceiling also acts as the floor on the first floor (two-storey house).

Other surface temperatures such as walls, glass and doors also show high temperatures. However, it must be taken into consideration that these surfaces have various orientations with respect to the sun, which also causes variations. As an example, the wall temperature of M6.a is up to $42.9^0$C in the morning and $44.50^0$C in the afternoon, which is extremely high for wood plank, compared with the outside temperature $31.3^0$C, $30^0$C respectively for morning and afternoon (appendix B). The measurement was conducted on the west and east orientation, hence the higher wall temperature compared with the north south walls, which were $32^0$C. The north-south orientation is the recommended position in the tropic zone to locate the openings since it can provide a comfortable day light with mild temperature. Numerous orientations of measurement were carried out because the houses have various designs with regard to the opening positions and the house exposures.

The floor also shows a high temperature, even though most of them are constructed from tile and cement, which have a reasonable thermal mass and may therefore be expected to absorb a large amount of heat without an increase in temperature. It may be a result of radiation from all the other surfaces with high temperatures.

Table 6.6 also shows the overall performance of temperature difference between the outside air temperature and the inside surface temperature. The heavyweight house shows that the ceiling has the lowest ability in reducing the outside temperature meaning that it suffers the highest surface temperature, followed by glass, wooden door, floor, and wall respectively. The lightweight house shows that all surfaces except the floor have higher temperature than the outside air temperature with the highest one being measured at the ceiling. This would be expected since warm air rises and would contribute further convective heating to the ceiling. The higher surface temperature of the building envelopes during the day is also caused by the character of light weight materials that warms up quickly when the sun shines in or the heating comes on; and conversely cools down equally as fast (Bird, 2010). Conversely, the semi permanent house shows a quite good performance in that all inside surface temperatures are lower than the outside air temperature.

The inside air velocity shown in the table 6.6 is quite low for cooling such hot inside temperatures. The average range of air speed 0.06-0.27 m/s is much lower than the outside air speed and too low to have any influence in a warm environment. The houses are shown to have inappropriate openings for allowing the outside air speed to decrease the inside air temperature. Arens et. al. (2009) through their extensive survey of air speed in neutral and warm environments found that once thermal sensation is >2.5 (hot), 94.45% of people prefer to have the air speed higher than 0-0.2m/s of air speed range. Even for the 'neutral thermal sensation (0)', about 45.92% of people still prefer the air speed higher than 0-0.2m/s. This confirms the result of this survey which is that only 20% of households feel that the mean rate in their houses is too strong while another 80% feels that it is roughly light.

## 6.8 Assessment of comfort votes and thermal acceptability

In common studies dealing with thermal comfort many researchers use the adaptive approach which obtains the neutral temperature based on the observation of people's behaviour in relation to their environment. As previously explained, the adaptive approach is commonly carried out by using the thermal comfort vote such as ASHRAE or Bedford scale. Another common methodology conducted in describing the actual vote is asking the people's thermal sensation simultaneously with the internal temperature measurement. The traditional methods used for calculating a neutral temperature from field survey data are regression analysis to calculate the temperature which will give an average comfort vote of neutral or probit analysis to calculate the Operative Temperature at which the greatest number of people will be comfortable (Nicol et. al., 2009).

In this survey, the researcher aims to find out the overall thermal performance of the ten types of permanent post tsunami housings. The methodology commonly used by many researchers is difficult to apply in this case. Since the measurement was conducted over 2 days for each house, people seemed to find the task of filling in the questionnaire by themselves for such a long time to be too onerous, although they are mostly able to write or to read. Therefore in this survey the questionnaire was filled by the surveyors by only asking their mean thermal sensation vote during morning, afternoon and evening throughout the year and their preference with regard to providing more comfortable conditions. Meanwhile the thermal logger was left measuring over two days. The seven thermal sensation scales in the questionnaire implies the ASHRAE scale, namely -3, -2, -1, 0, 1, 2, 3 representing cold, cool, slightly cool, neutral, slightly warm, warm and hot respectively. This vote elicits the people's general feelings in the morning, afternoon and evening. However, due to the difficulty previously mentioned, the vote is only used to find out the general thermal performance of the houses which is shown in figure 6.10 and table 6.8

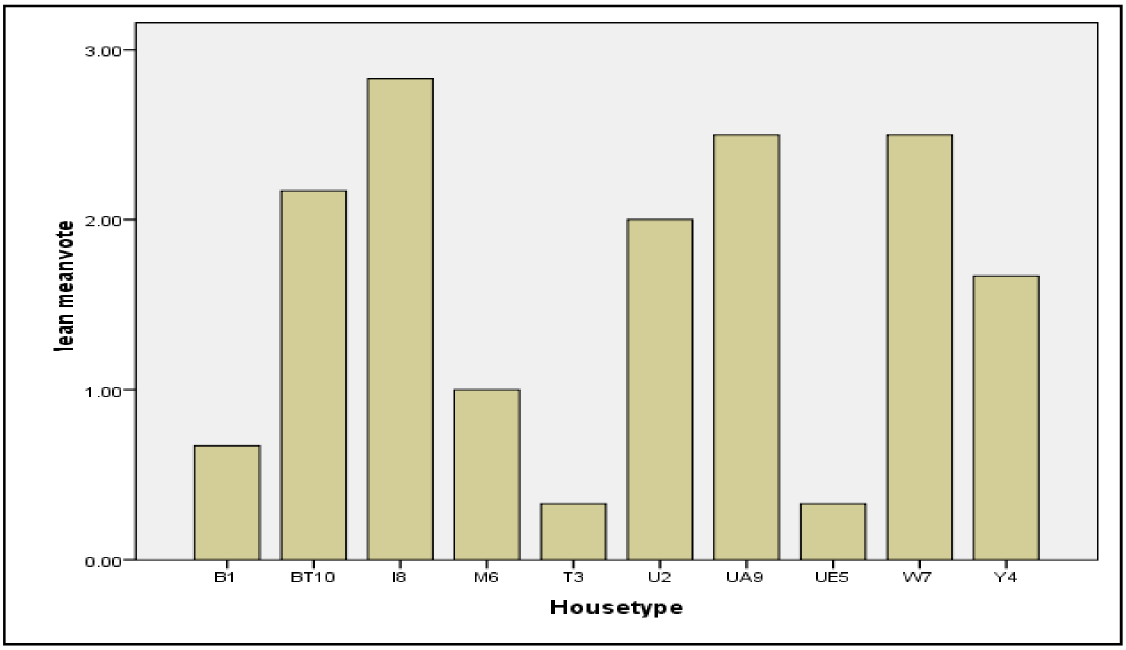



Figure 6.10. General thermal mean vote of all house types

The most interesting relationship is the correlation between the thermal sensation vote and the quality of house design. During the observation, the researcher found that T3 and UE5 have a better performance compared with other types, at the same time this type is voted 0.33 on the thermal sensation scale by the households which is most thermally comfortable (figure 6.10). Both of these types are heavy construction using plastered brick as the wall, tiled floor and aluminium roof. They are actually not so much different from other masonry houses; the significant things are these houses are tidily built and attractive. The households of T3 commented that their houses were nice and they got enough air circulation throughout the rooms. The other subjective consideration is its suburban location that is not directly in contact with pollution and other heat emission from traffic. Meanwhile UE5 has a very good performance with high ceiling and good design of ventilation. The mean inside air temperature is actually 31.9$^0$C which is actually not so much different from inside temperatures of other types. Yet, this house is voted thermally comfortable by the households even though some of them use air conditioner in their bedroom during the night.

Table 6.7. Average of thermal mean votes

| House types | Thermal Mean Votes | Std. Deviation |
|---|---|---|
| light | 2 | 0.93 |
| half permanent | 1.84 | 0.23 |
| heavy | 1.27 | 1.13 |

The worst thermal performance is voted by the households of I8 (figure 6.10) with the thermal sensation vote 2.83 (warm-hot). This is reasonable as we see the house design is far from what people want. This type is actually the temporary house where the tsunami victims dwell while they are waiting for permanent houses. But many people still live in there for an unknown length of time, even though many permanent houses have been built. Since this study only sees the environmental performance, no deep investigation was conducted to know their reason for them to keep living in that house. This house is constructed from one layer of 3-6 mm calsiboard wall, cemented floor and zinc roof that also acts as the ceiling which suffers the highest ceiling temperature which is up 43$^0$C. The house also looks untidy in terms of the construction.

Table 6.7 shows the average of the subjective thermal sensations voted by the household grouped in 3 house types. The heavy weight house type is voted as the most thermally comfortable one, with the scale of 1.26 (slightly warm) and followed afterwards by half permanent house and the light weight house. Apart from the thermal condition of those houses, these votes are also believed to be highly related to the house condition as previously explained.

However, the result of the thermal measurement carried out to all of those house types shows that the half permanent house has a better indoor thermal performance compared with others. Yet, this house type is not built as tidy as the masonry house and moreover without adequate space for cooking activity. Therefore, this house type may not be voted most thermally comfortable.

## 6.9 Indoor thermal condition corresponding with the orientation toward the sun

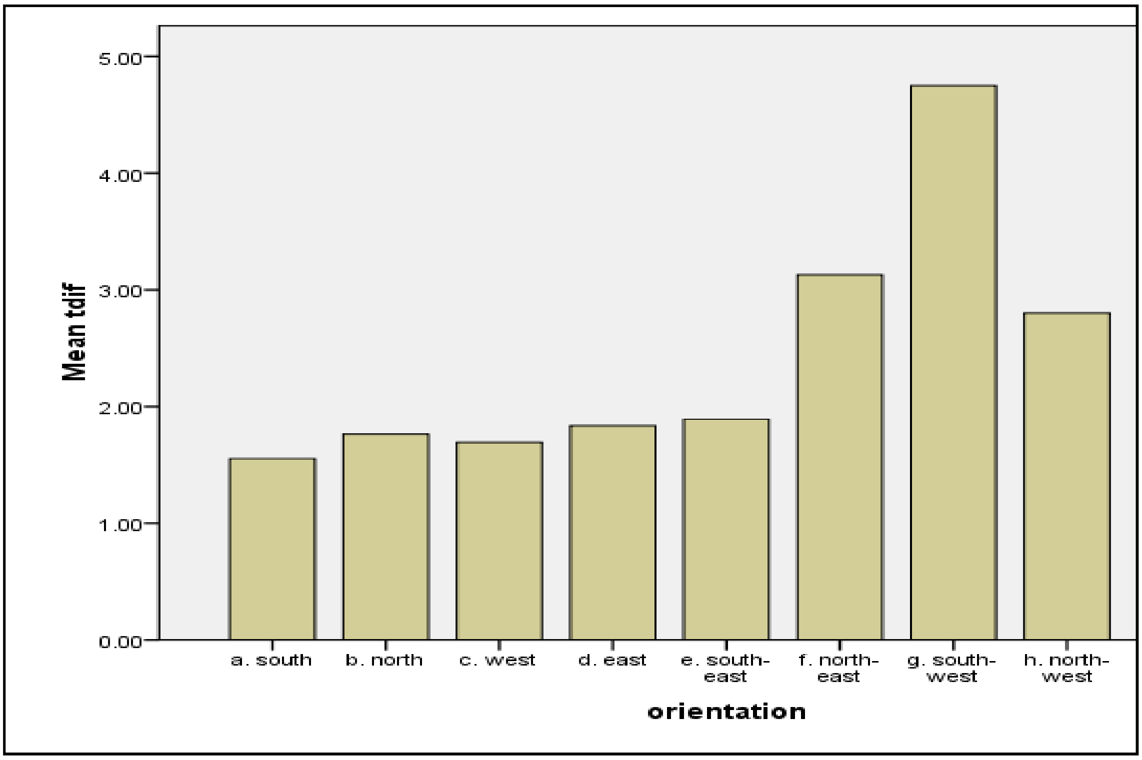



Figure 6.11 Indoor thermal conditions corresponding with the orientation toward the sun

The temperature differences between the outdoors and the indoors measured over one hour during the day collected from 188 post tsunami houses show that the front houses orienting south and north have lower inside air temperature than others facing other orientations (figure 6.11). The front houses are normally built with sufficient openings, while other sides are sometimes obstructed by neighbors' walls. Apart from the slightly small values of temperature difference among the house facing south, north, west, east and south east; it appears to comply with the theory that north and south front facing will reduce the overheating.

### 6.10 Day lighting performance

Figure 6.12 shows that daylight performance inside the house varies considerably. There is little consistency between the house type and daylight provision. The same type houses have different daylight performance. Even in one house, the bed and the living room are daylit differently. During the measurement, we let the householders continue in their daily habits such us closing or opening doors and windows. The bedroom had a lower illuminance compared with the living rooms since the windows of the bedrooms were mostly closed (figure 6.13) or their opening faces other neighbours' wall obstructing their full day light.

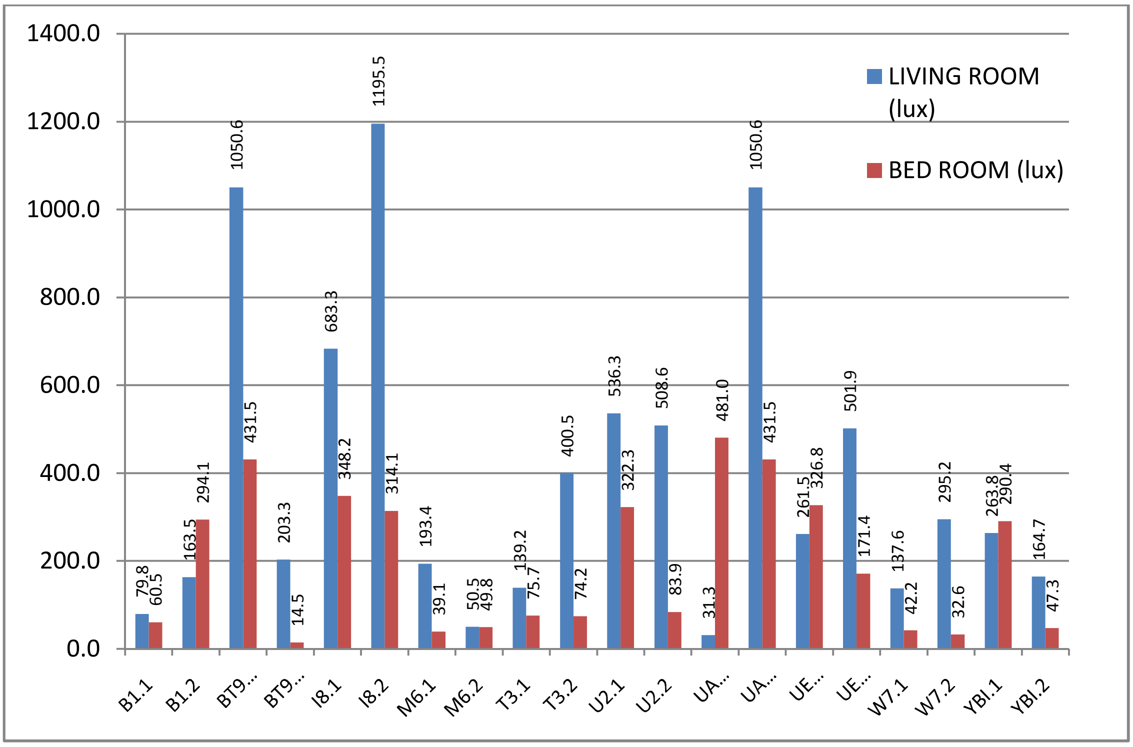



Figure 6.12 Day lighting performance

Figure 6.13 Muslim aid house resembling Acehnese traditional house

The Acehnese traditional looking houses (M6) have smaller window sizes compared with other house types and they are built in wooden jalousie not glass. Hence, once the window is closed, the indoor illuminance will be automatically low, with 84.17 lux on average.


Figure 6.14 Unintended roof leakage letting the sun light come in to the house

I8 houses have the higher indoor illuminance (635.26 lux). The sunlight does not only come from the window glass but also from the roof leakage (figure 6.14). More light coming from the roof creates more heat transferred in to the house. Therefore this house suffers the highest inside air temperature among the post tsunami houses.

### 6.11 Two months thermal data collection

A longer thermal data collection was carried out from May 24th- July 6th, 2009 in one of the post tsunami houses. This house is the heavy weight house provided by UN Habitat which was designed as typical as the most house donors do. This masonry house was selected because it is the common house type preferred by most of the tsunami victims. (Arup, 2006). This house is designed in $36m^2$, 2 bed rooms, kitchen and toilet. It is constructed with the tiled floor, cemented brick wall, and zinc roof.

Figure 6.15 The house donated by UN Habitat measured over 45 days

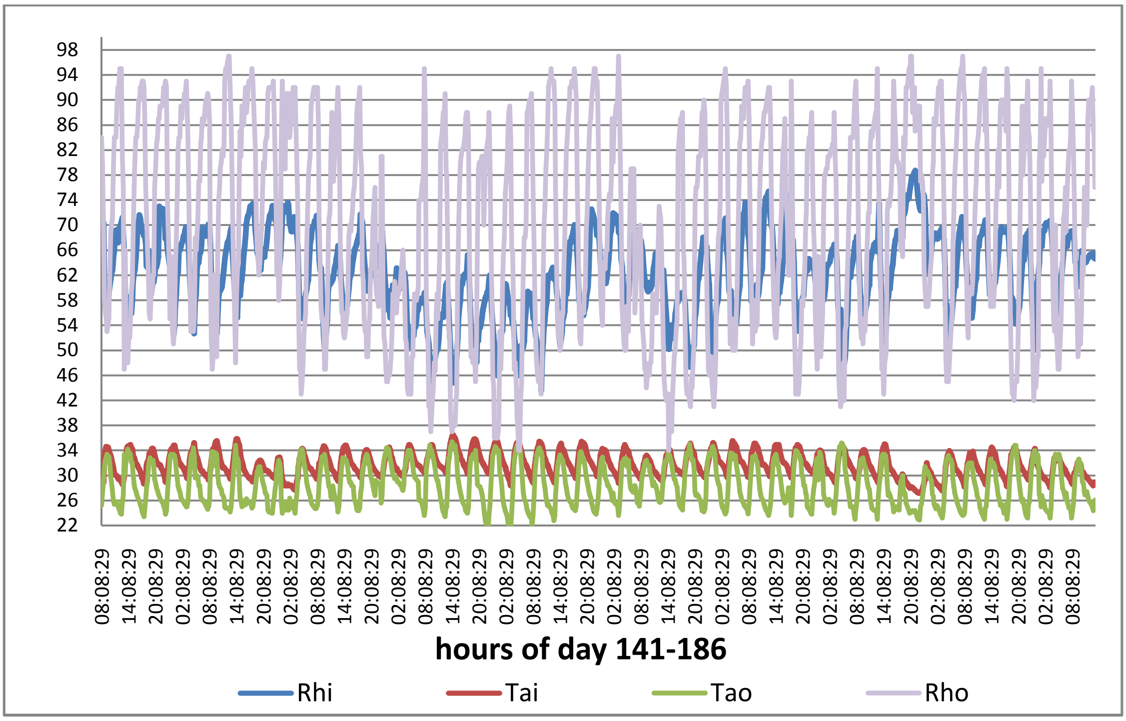



Figure 6.16 Indoor thermal performance of UN Habitat house

The result shows that the average inside air temperature is $31.7^0C$ which is higher by $3.2^0C$ than the average outside air temperature. During the day it reaches its peak inside air temperature up to $36.5^0C$ while the peak outside temperature is $35.4^0C$. During evening, night and early morning, the inside air temperature is by 5.6 higher than the outside air temperature.

Table 6.8 Indoor thermal performance of UN Habitat house

| | RHi (%RH) | Tai (°C) | Tao (°C) | Rho (%RH) | t dif (tai-tao) (K) |
|---|---|---|---|---|---|
| avg | 62.1 | 31.7 | 28.5 | 70.1 | 3.2 |
| max | 78.7 | 36.5 | 35.4 | 97.0 | 1.1 |
| min | 43.6 | 27.2 | 21.6 | 34.0 | 5.6 |

### 6.11.1 Indoor Thermal performance in Acehnese Traditional Houses

Traditional vernacular architecture has been found to be adapted with the local climate. Therefore in this study, three Acehnese traditional houses and one post tsunami house resembling the Acehnese traditional house were measured to get the comparison. The four measured houses are described as follows:

#### a. AT1

This Acehnese traditional house is designed with the typical traditional house materials that were used previously by the real Acehnese house. The roof is constructed from sago palm leaf/ grass (thatch) and the overall walls are from timber. And the floor is raised up to 2.5-3 meters above the ground. The high roof allows air to circulate as shown in the following figure. The surroundings are maintained with greenery. This house is only occupied occasionally for some special cases or events.

The measurement was conducted from June 9th-July 3rd, 2009. The inside and outside air temperature and relative humidity were recorded simultaneously every ten minutes.

Figure 6.17 Acehnese traditional house (AT1)

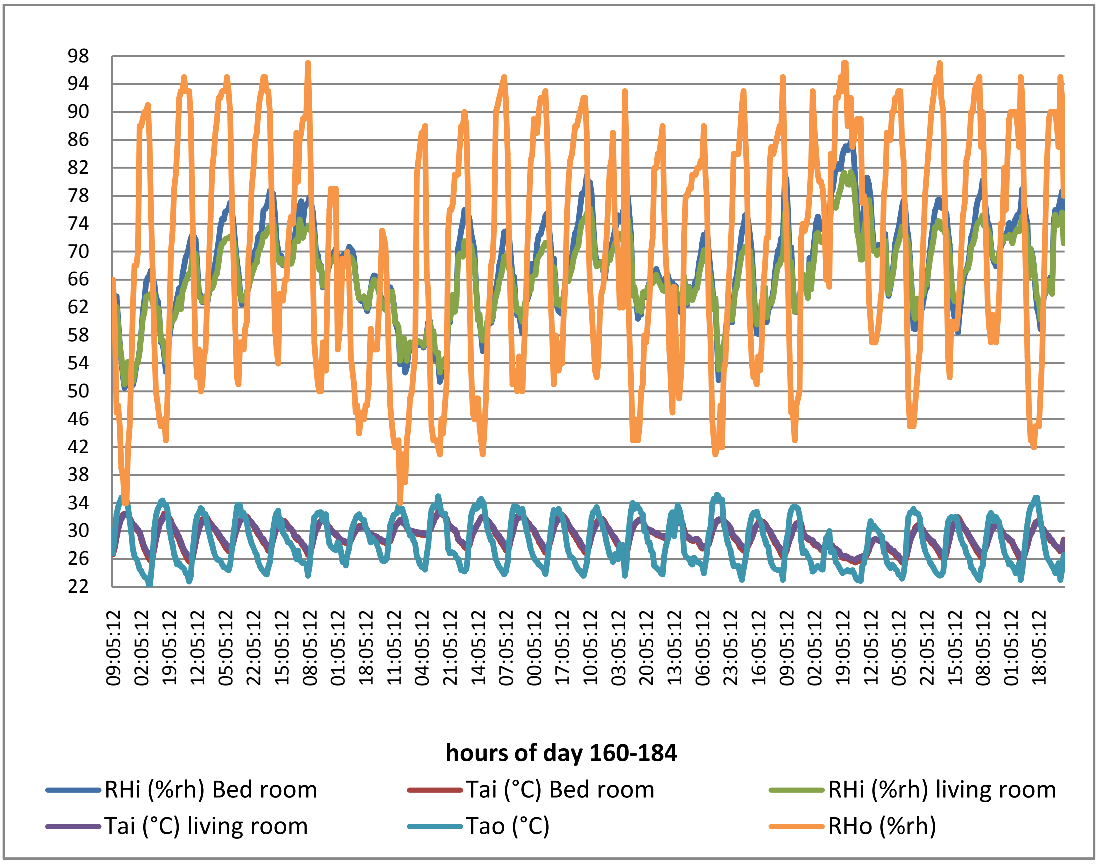



Figure 6.18 Indoor thermal performance of house AT1

Table 6.9 Summary of indoor thermal performance of house AT1

| | RHi (%RH) Bed room | Tai (°C) Bed room | RHi (%RH) living room | Tai (°C) living room | Tao (°C) | RHo (%RH) | T diff (K) (living room) |
|---|---|---|---|---|---|---|---|
| AVG | 67.7 | 29.3 | 66.6 | 29.4 | 28.4 | 69.9 | 1.0 |
| MAX | 85.8 | 32.9 | 81.4 | 32.7 | 35.2 | 97.0 | -2.5 |
| MIN | 50.5 | 25.4 | 51.0 | 25.9 | 21.8 | 34.0 | 4.1 |

Table 6.9 shows that the inside air temperature is quite close to the outside air temperature. The average inside air temperature meets the Indonesian neutral temperature. Categorised as a light weight house, this house is shown to have much better inside thermal value compared with other light weight houses shown in the appendix B. Even though higher by 3°C than the neutral temperature, the peak inside air temperature in this house is lower by 3°C than the outside air temperature.

**b. AT2**

The second type is also constructed from the original traditional house material. The general performance is similar as AT1, only some parts of the internal roof surface (living room and bed room) are covered by plywood ceilings while other parts are sago palm leaf roof. This house is actively occupied by the householders. The measurement of the inside and the outside air temperature and the relative humidity was simultaneously carried out every ten minutes from July 6$^{th}$-14$^{th}$, 2009.

Figure 6.19 Acehnese traditional house (AT2)

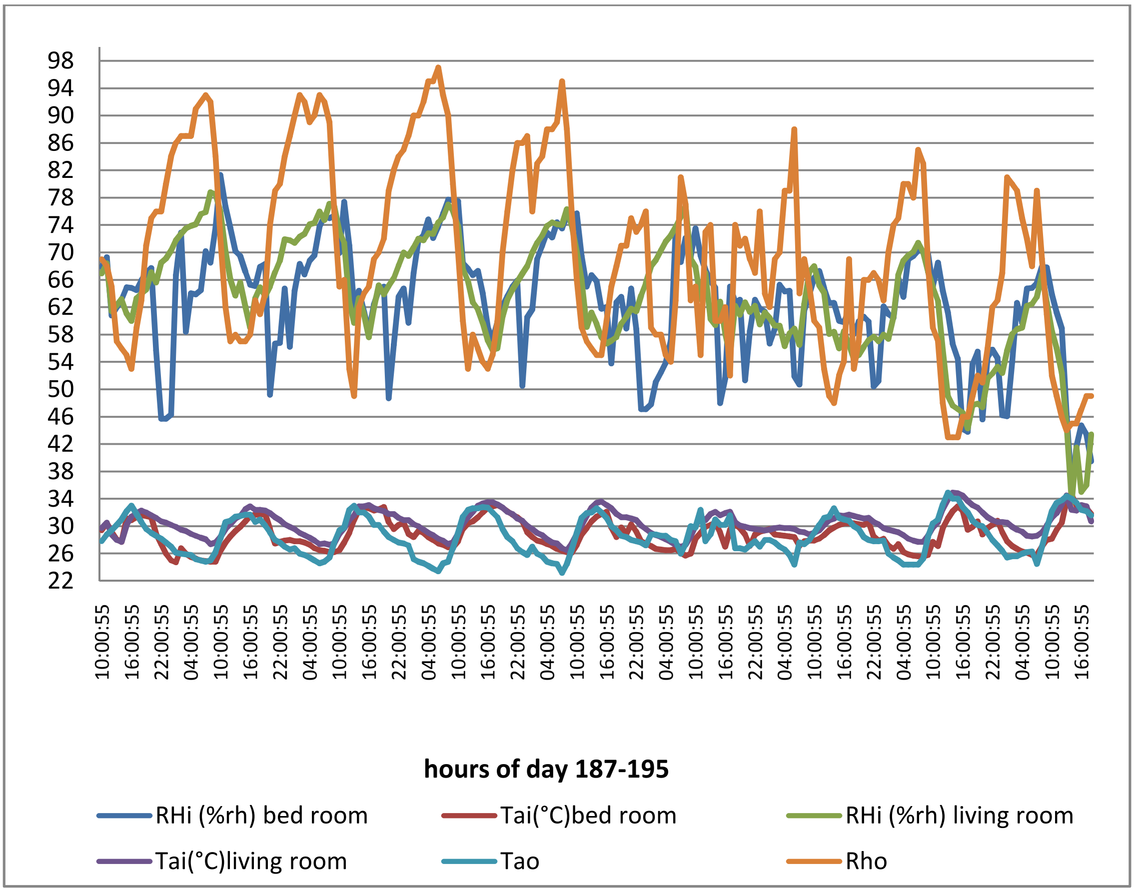



Figure 6.20 Indoor thermal performance of house AT2

Table 6.10 Summary of indoor thermal performance of house AT2

| | RHi (%RH) bed room | Tai(°C) bed room | RHi (%RH) living room | Tai(°C) living room | Tao (°C) | Rho (%RH) | Tdif (K) Living room |
|---|---|---|---|---|---|---|---|
| avg | 62.7 | 28.9 | 63.7 | 30.4 | 28.6 | 69.2 | 1.8 |
| max | 81.3 | 34.6 | 78.8 | 34.9 | 34.9 | 97.0 | 0 |
| min | 35.5 | 24.7 | 33.5 | 26.5 | 23.2 | 43.0 | 3.3 |

### c. AT3

This traditional house is built with the zinc sheet as the roof. The inner side is covered by a plywood ceiling. The layout and other materials of the house are similar to the first two types.

Figure 6.21Acehnese traditional house (AT3)

Both the outside and inside air temperature and relative humidity were collected from July 6th-14th, 2009 every ten minutes.

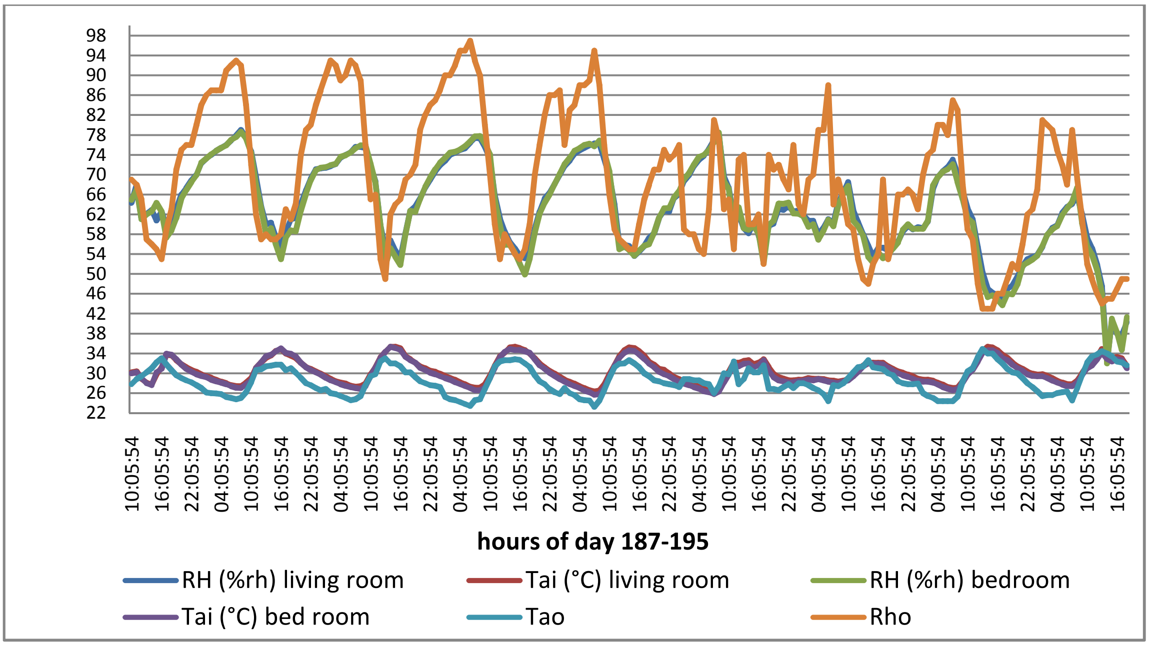



Figure 6.22 Indoor thermal performance of house AT3

Table 6.11 Summary of indoor thermal performance of house AT3

| | RH (%RH) living room | Tai (°C) living room | RH (%RH) bedroom | Tai (°C) bed room | Tao (°C) | Rho (%RH) | T diff (K) |
|---|---|---|---|---|---|---|---|
| avg | 63.3 | 30.5 | 62.9 | 30.1 | 28.6 | 69.2 | 1.9 |
| max | 79.0 | 35.3 | 78.6 | 35.3 | 34.9 | 97.0 | 0.4 |
| min | 32.5 | 26.3 | 32.0 | 25.7 | 23.2 | 43.0 | 3.1 |

## d. AT4

This is the Acehnese traditional house type provided by the donor for the tsunami victims. This house is smaller than the real traditional house. The roof is zinc sheet covered by the aluminium foil insulating the inner side. The wall is built from the 5 mm thick GRC sheet.

Figure 6.23 Post tsunami house resembling Acehnese traditional house (AT4)

The thermal parameters of AT4 house were collected from June 15$^{th}$-July 1st, 2009 as shown in the following chart.

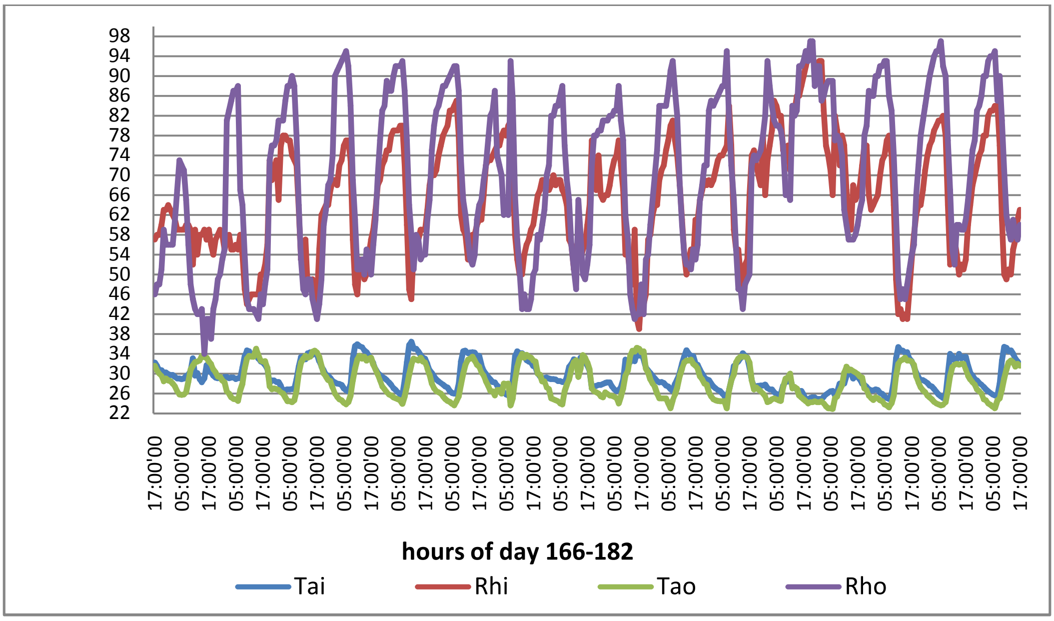



Figure 6.24 Indoor thermal performance of house AT4

Table 6.12 Summary of indoor thermal performance of house AT4

| | Tai (°C) | Rhi (% RH) | Tao (°C) | Rho (% RH) | Tdif (K) |
|---|---|---|---|---|---|
| Avg | 29.7 | 65.5 | 28.3 | 69.6 | 1.4 |
| Max | 36.4 | 95.0 | 35.2 | 97.0 | 1.2 |
| Min | 24.8 | 39.0 | 22.9 | 34.0 | 1.9 |

### 6.11.2 Discussion on Indoor thermal performance in Acehnese traditional houses

The following bar chart (figure 6.25) shows that AT1 house has the best performance among the four houses. It has low maximum temperature which is about $2^0$C lower than the peak outside air temperature. This can be understood that this house is designed with originally traditional building materials which has low thermal mass. The surrounding house is also shaded with high trees. The unfrequent occupancy also becomes the reason to have low inside air temperture due to the little influence of sensible heat from equipment and appliances operated in the house. From the maximum bar, we see that the best performances following after AT1 are AT2, AT3 and AT4 respectively. It can be understood that AT3 and AT4 use zinc roof instead of thatch causing higher inside air temperature. AT4 worsens the condition by using single GRC sheet, while other houses are built with real wood.

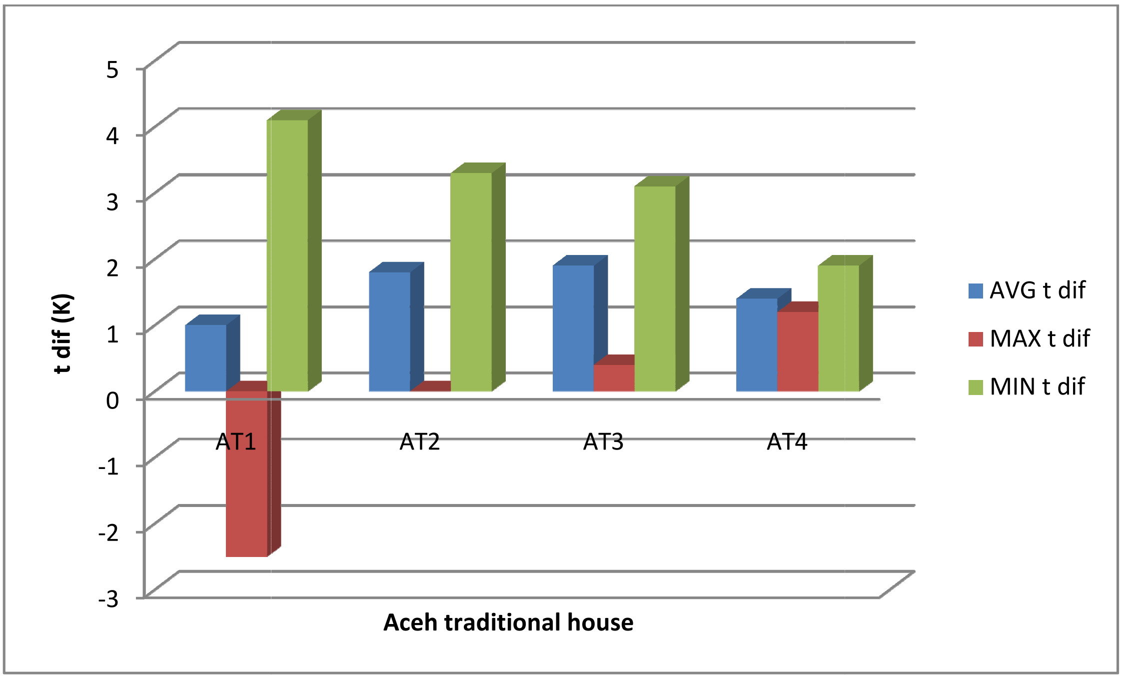



Figure 6.25 Comparison of temperature difference (tai-tao) in Acehnese traditional houses

The minimum inside air temperatures in the houses are higher than the outside value. It can be caused by the closed apertures during the night. However the values are not more than the neutral temperature range.

The outside relative humidity in Aceh is predominantly high which is shown in the measured weather data. Figure 6.26 shows that most of the time, inside relative humidity is lower than the outside value yet on average is still higher than 60% (the upper comfort limit of RH value). The peak RH value (mostly occuring during the night) of AT4 is shown to be the highest compared with other houses. While during the day where RHvalue  is lower than 40%, the RH value in AT1 is slightly higher than 50%.

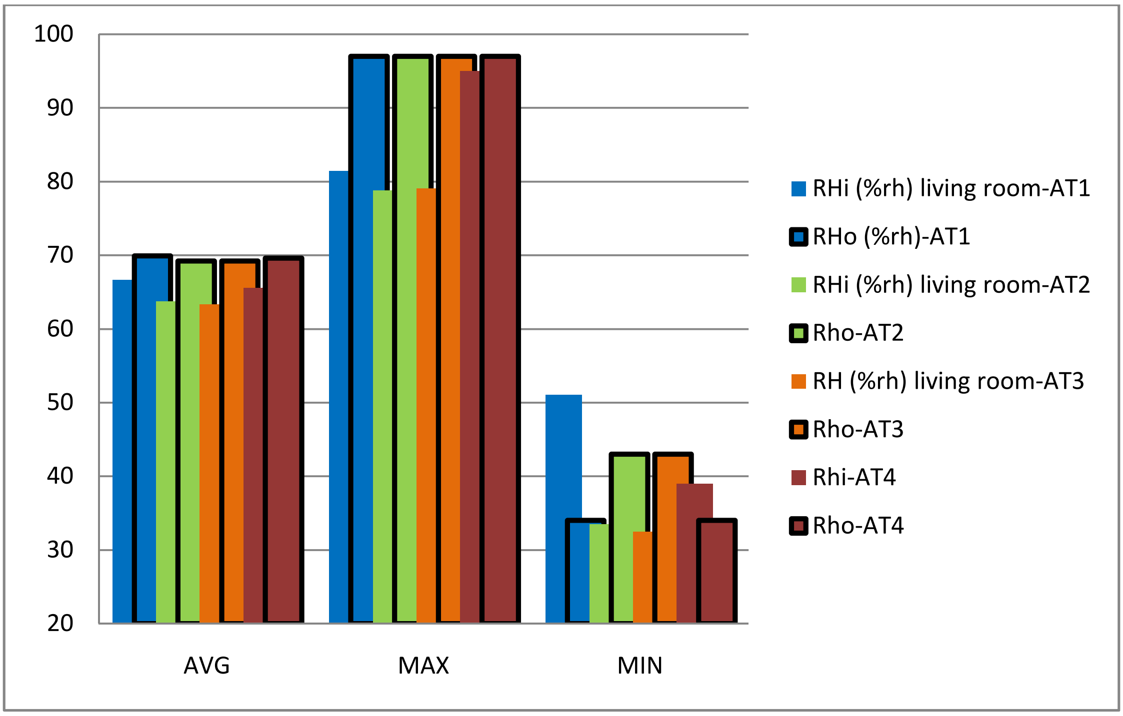



Figure 6.26 Performance of Relative Humidity in Acehnese traditional houses

### 6.11.3 Indoor thermal performance in unaffected tsunami houses

During the survey, three houses that were not affected by the tsunami were also measured. These three houses (UTH1, UTH2, and UTH3) are characterized by the different building materials and designs.

**a. House one (UTH1)**

Figure 6.27 House one (UTH1)

This house is a masonry house which consists of two parts. The first part is the front part, the one storey house which was originally built by the house council. The second part is the rear side, two-storey house which was additionally built by the householder. The measurements was carried out on the ground floor of the second part to see how the house built by the householder deals with indoor comfort (figure 6.27). The measured part is constructed with an aluminium roof, cement plastered brick wall, 3 meters high concrete ceiling and ceramic tiled floor.

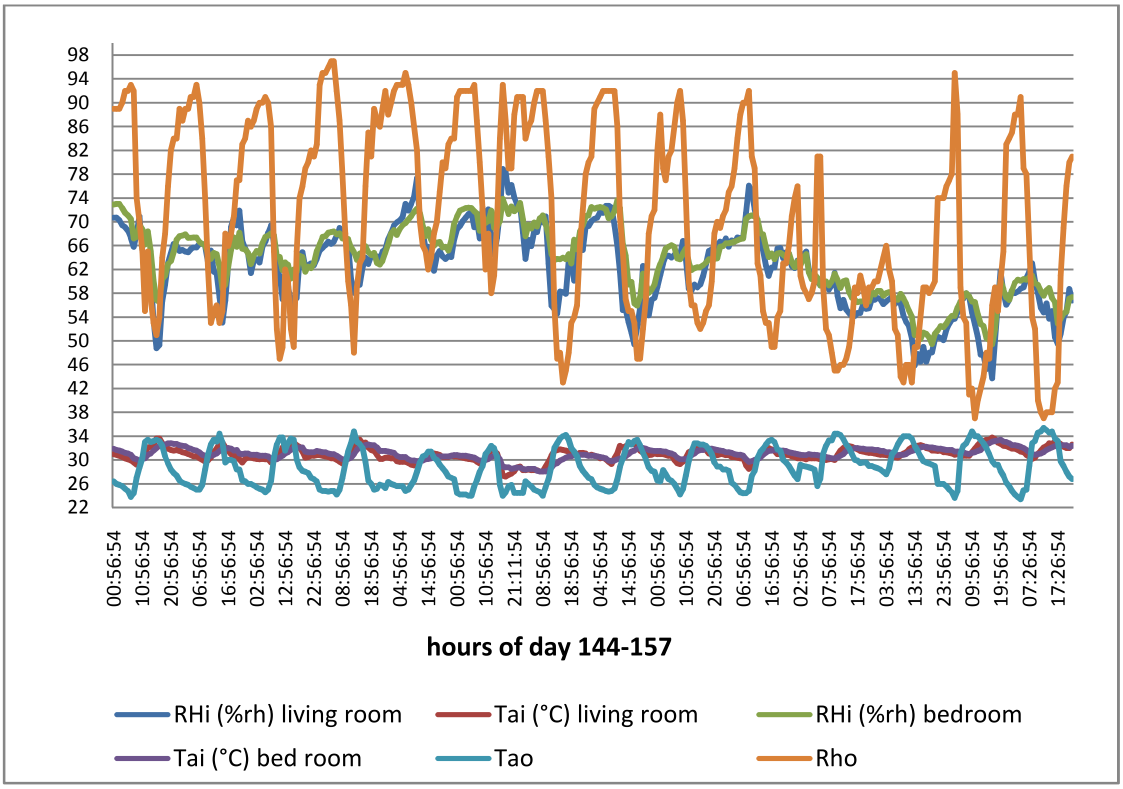



Figure 6.28 Indoor thermal performance of house UTH1

Table 6.13 Summary of indoor thermal performance of house UTH1

| | RHi (%rh) living room | Tai (°C) living room | RHi (%RH) bed room | Tai (°C) bed room | Tao (°C) | RHo (%RH) | T diff (K) |
|---|---|---|---|---|---|---|---|
| avg | 62.2 | 30.9 | 63.7 | 31.1 | 28.8 | 70.5 | 2.1 |
| max | 78.9 | 33.8 | 73.9 | 33.4 | 35.4 | 97.0 | -1.6 |
| min | 43.7 | 27.2 | 49.4 | 28.1 | 23.4 | 37.0 | 3.8 |

The measurement of thermal parameters was made from May 24$^{th}$- June 8$^{th}$, 2009, every ten minutes. The bedroom temperature is slightly higher than the living room. Meanwhile, the peak inside air temperature of the two rooms is lower by 2°C than the outside value.

### b. House two (UTH2)

House two is the half permanent house which was individually built by the householder. There is no information when this house was built, yet the performance shows that it is quite an old house. This house is constructed with zinc roof, cemented floor and half permanent wall (plastered brick and ply wood).

Figure 6.29 House two (UTH2)

The thermal measurement in this house was conducted every ten minutes from June 5th-July 2nd, 2009.

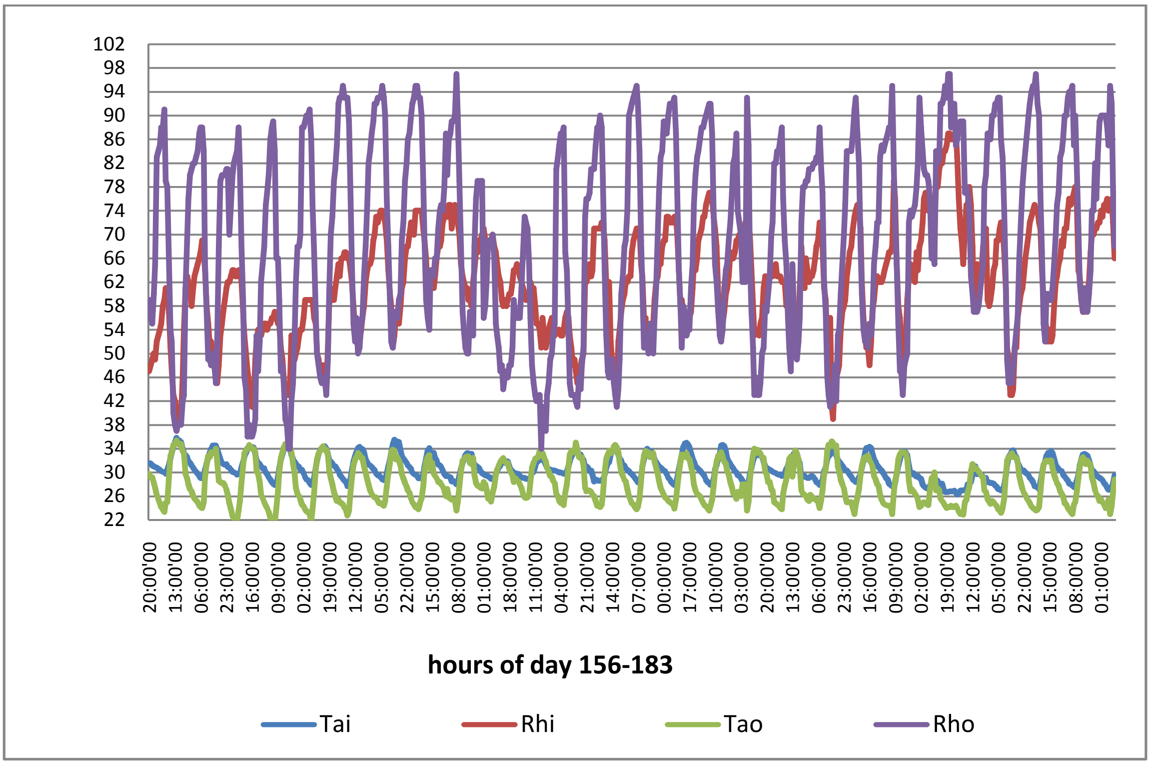



Figure 6.30 Indoor thermal performance of house UTH2

Table 6.14 Summary of indoor thermal performance of house UTH2

| | Tai (°C) | Rhi (%RH) | Tao (°C) | Rho (%RH) | Tdif (K) |
|---|---|---|---|---|---|
| AVG | 30.7 | 62.0 | 28.3 | 69.4 | 2.4 |
| MAX | 35.8 | 87.0 | 35.4 | 97.0 | 0.4 |
| MIN | 26.3 | 39.0 | 21.6 | 34.0 | 4.7 |

Table 6.14 shows that the average inside air temperature is by 2.4 °C higher than the outside value. The maximum inside air temperature is just nearly equal to the outside maximum value.

### c. House three (UTH 3)

The third house was built by the Indonesian State-Owned Enterprises (SOEs) about 35 years ago. This house originally had a 2.8 meter high asbestos ceiling, but since the householder increased the height of the floor surface up to 50 cm in order to avoid the flooding that often happens in that area, the wall height is now only 2.2 meters. This house is constructed from cement plastered brick outside wall and two layers of plywood as the inside wall, cemented floor, and zinc roof.

Figure 6.31 House three (UTH3)

The thermal measurement in this house was conducted every ten minutes from June 8th-15th, 2009.

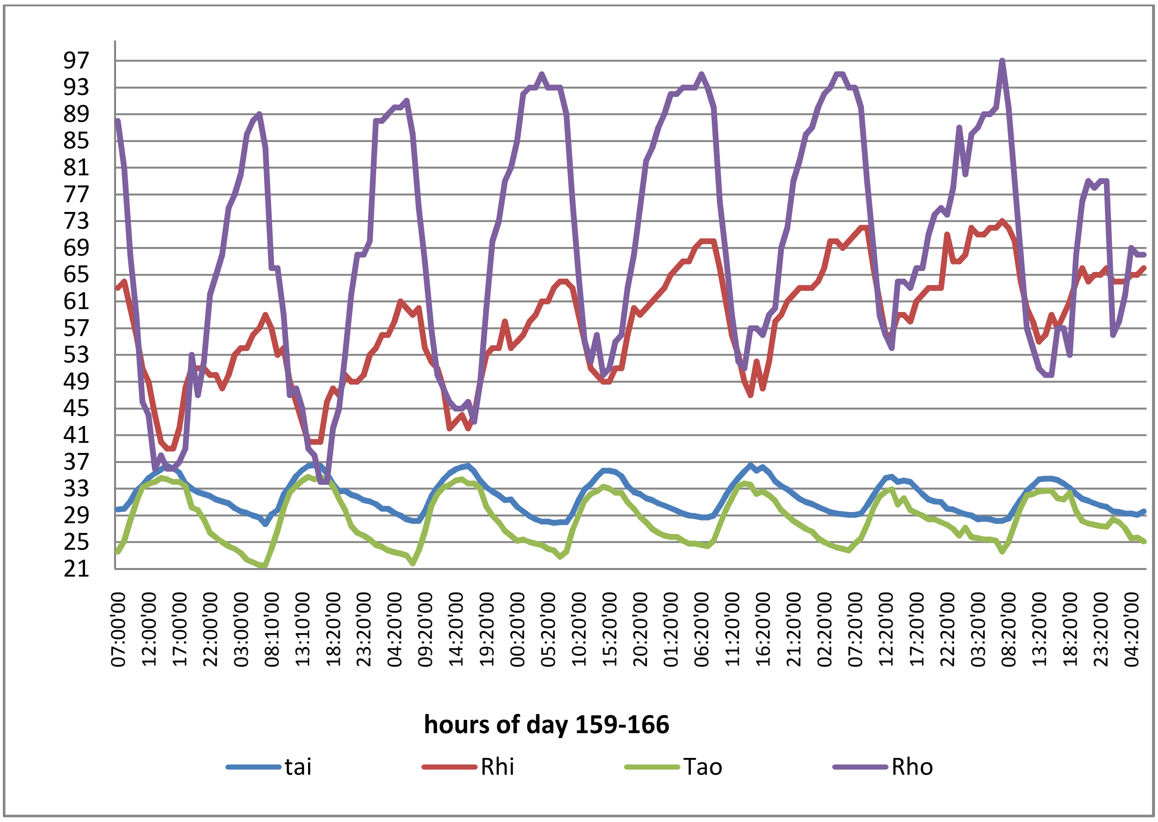



Figure 6.32 Indoor thermal performance of house UTH3

Table 6.15 Summary of indoor thermal performance of house UTH3

| | Tai (°C) | Rhi (%RH) | Tao (°C) | Rho (%RH) | Tdif (K) |
|---|---|---|---|---|---|
| AVG | 31.7 | 57.7 | 28.4 | 69.3 | 3.3 |
| MAX | 36.5 | 73.0 | 34.8 | 97.0 | 1.7 |
| MIN | 27.7 | 39.0 | 21.6 | 34.0 | 6.1 |

The results show that this house has quite high inside air temperatures. The peak value is 2 °C higher than the peak outside value. Similar to house UTH2, during the day the relative humidity is quite low, just slightly higher than the outside value.

### 6.11.4 Discussion on Indoor thermal performance in unaffected tsunami houses

Figure 6.33 shows the comparison of thermal performance in the houses typically occupied by the Acehnese people that were not affected by tsunami. The overall concrete house (UTH1) is shown to be the most able to reduce the high peak outside temperature. Meanwhile house UTH3 shows a poor ability to deal with high outside temperature that might be influenced by the low height of ceiling that is only 2.2 meter while others are up to 3 meter high.

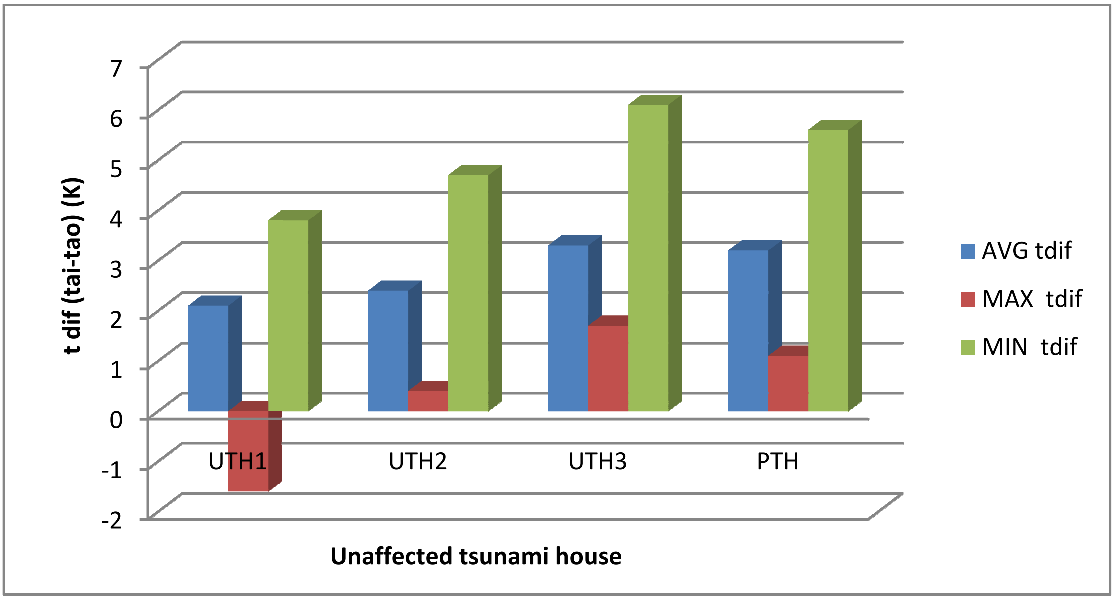



Figure 6.33 Comparison of temperature difference (tai-tao) in unaffected tsunami houses with post tsunami house

However, all of the measured unaffected tsunami houses have higher average inside air temperature compared with the average outside value. Even worse with the minimum temperature mostly occurring during the night, where the houses suffer much higher inside air temperature than the outside ones. The heavy weight construction, highly sealed house and limited apertures to let the air come through are believed to be the reasons for the conditions.

Figure 6.33 shows that the inside air temperature in the typical post tsunami house (PTH) measured over 45 days is almost similar to the value in UTH3 (the worst performance among the three unaffected tsunami houses). We may conclude that the house donors built the houses applying the typical house building methods. It is believed that there was no previous assessment of indoor thermal comfort hence no improvements in getting better and lower inside air temperature.

## 6.12 Comparison of Mean inside temperature

Table 6.16 shows that Acehnese traditional house has the lowest inside air temperature among the houses. The average inside air temperature is closed to the upper range of Indonesian comfort temperature. It also has lower peak temperature value than the outside one, whereas post tsunami and unaffected tsunami houses are only able to have similar peak inside temperature to the outside ones. This demonstrates that the traditional house has been well designed by understanding the local climate.

Table 6.16 Mean inside temperature in 3 house types

| | mean temperature $^0$C | | | | | |
|---|---|---|---|---|---|---|
| House category | tai-avg | tao-avg | tai-max | tao-max | tai-min | tao-min |
| Post tsunami -heavy weight house | 30.7 | 28.2 | 33.3 | 34.2 | 28.5 | 23.2 |
| Post tsunami- semi permanent house | 30.6 | 29.1 | 34.4 | 34.1 | 27.5 | 23.9 |
| Post tsunami-light weight house | 30.8 | 28.6 | 35.9 | 34.5 | 26.7 | 23.5 |
| Unaffected tsunami -heavy weight house | 30.9 | 28.8 | 33.8 | 35.4 | 27.2 | 23.4 |
| Unaffected tsunami - semi permanent house | 30.7 | 28.3 | 35.8 | 35.4 | 26.3 | 21.6 |
| Unaffected tsunami -light weight house | n/a | n/a | n/a | n/a | n/a | n/a |
| Acehnese traditional house | 29.4 | 28.4 | 32.7 | 35.2 | 25.9 | 21.8 |

There is no significant difference in average inside temperature among the three types of those houses (heavy, light weight and semi permanent). The mean inside temperature of all of those types is 30$^0$C. Nevertheless, table 6.15 explains that the heavy weight house, due to its thermal mass character, can have a lower inside air temperature than the outside value. As a result, conversely it has higher minimum temperature when the sun is down. Meanwhile the light weight house works conversely by having the highest inside peak temperature and the lowest minimum temperature among the three house types. The last house type, the semi permanent house, is likely to have similar peak inside air temperature to the outside value.

### 6.13 Neutral temperature

In order to obtain the neutral temperature which then can qualify the inside temperature of each house, the researcher used the data obtained by other studies and employed the model of finding the neutral temperature in natural ventilated buildings of Humpreys, Auliciems, Griffiths and Nicol (Equations 1-4), and the neutral temperature proposed by Karyono based on his study in Jakarta (Karyono, 2000). The mean outside air temperature used in equations 1-4 is 28.6°C which is the data obtained during the measurement May-July 2009.

Table 6.17 shows that the mean inside temperature in the traditional Acehnese house is close to the comfort temperature proposed by Nicol and even meets the comfort temperature range proposed by Karyono that may be more applicable, since his work was carried out in Indonesia. Meanwhile, the mean and the peak inside temperatures of post tsunami and unaffected tsunami houses are much higher than any of the comfort temperatures proposed by all of those thermal comfort experts, which supports the views of the 60% of post tsunami house holders saying that their houses are warm-hot.

Table 6.17 Comfort temperature comparison

| | Inside air temperature during the measurement May-July 2009 (°C ) | | temperature difference (°C ) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Humpreys tn = 27.1 | | Auliciems tn = 27.9 | | Nicol tn = 27.9[a] tn =28.8[b] | | Karyono tn = 23.9-29.7[c] | | Griffiths tn= 24.9[d] | |
| House types | peak tai | mean tai | peak tai-tn | mean tai-tn | peak tai-tn | mean tai-tn | Peak [b] tai-tn | Mean [b] tai-tn | peak [c] tai-tn | mean [c] tai-tn | peak[d] tai-tn | mean [d] tai-tn |
| Post tsunami - heavy weight | 33.3 | 30.7 | 6.2 | 3.6 | 5.4 | 2.8 | 4.5 | 1.9 | 3.6 | 1 | 8.4 | 5.8 |
| Post tsunami- semi permanent | 34.4 | 30.6 | 7.3 | 3.5 | 6.5 | 2.7 | 5.6 | 1.8 | 4.7 | 0.9 | 9.5 | 5.7 |
| Post tsunami- light weight | 35.9 | 30.8 | 8.8 | 3.7 | 8 | 2.9 | 7.1 | 2 | 6.2 | 1.1 | 11 | 5.9 |
| Unaffected tsunami -heavy weight | 33.8 | 30.9 | 6.7 | 3.8 | 5.9 | 3 | 5 | 2.1 | 4.1 | 1.2 | 8.9 | 6 |
| Unaffected tsunami - semi permanent | 35.8 | 30.7 | 8.7 | 3.6 | 7.9 | 2.8 | 7 | 1.9 | 6.1 | 1 | 10.9 | 5.8 |
| Acehnese traditional | 32.7 | 29.4 | 5.6 | 2.3 | 4.8 | 1.5 | 3.9 | 0.6 | 3 | -0.3 | 7.8 | 4.5 |

*a : Nicol's first survey in Pakistan*

*b : Nicol's second survey in Pakistan*

*c :The upper range of comfort temperature in Jakarta studied by Karyono based on the PMV range: -1<PMV<1*

*d : The equation using Griffiths constant is also applied by using the Griffiths constant (G) of 0.5 which is recommended to avoid in the predictor variable and the running mean constant (α) of 0.8 (half a week) as the sample (it refers to equation: 0.331Trm + 18.8). The average of outside temperature during the measuring period (May, 20$^{th}$-July, 14$^{th}$ 2009) is about 28.6 $^{0}$C with standard deviation of 1.15 which seems to have not so many differences among them, hence the value of Trm applied is a sample of date June, 30$^{th}$ 2009 which suffered the highest mean outside temperature and another 4 days before that date (using equation 6 and 7). By using that consideration, the Trm used is 18.4$^{0}$C hence the obtained neutral temperature is 24.9$^{0}$C.*

Table 6.17 also shows that the neutral temperature using the Griffiths constant is quite low. The equation using Griffiths constant is adopted from the paper of Nicol et.al. (2010) dealing with EU project Smart Controls and Thermal Comfort (SCATs), hence its lower result of neutral temperature is more reasonably applicable in the European case. Meanwhile, the neutral temperature result using the Nicol second models and Karyono seems to be more applicable in Banda Aceh case, a warm humid area, since they give quite small differences between the mean inside temperature of houses measured in this study and the comfort temperature obtained from those equations.

The study also shows that there is no significant difference of inside air temperature between the post tsunami houses and the unaffected tsunami houses (except Acehnese traditional house). The inside air temperature values stand higher than the neutral temperature applicable in Indonesia. This confirms that the post tsunami housing was built fully the same as the currently typical houses in Aceh.

### 6.14 Conclusion

In this chapter, the inside thermal performance of post-tsunami housing based on the house types and house designs collected during the survey are presented. In general, the measured houses are categorised into heavyweight, semi-permanent and lightweight houses. Due to the thermal mass character, during the day, heavyweight houses were shown to have lower inside air temperatures than the outside value. While from the longer measurement, the heavyweight houses were shown to give the pattern of higher inside air temperature values than the outside value during the absence of the sun. In contrast, during the day, the lightweight houses tended to have higher inside air temperature than the outside value. Having the character of warming up quickly when the sun shines in or the heating comes on; and conversely cooling down equally as fast (Bird, 2010) makes the lightweight house to have a lower inside air temperature than the value in heavyweight houses during periods of sundown.

In this study, the occupants were also asked to rate their thermal sensation of their houses. By using the ASHRAE scale (-3: cold; -2: cool; -1: slightly cool; 0: neutral; 1: slightly warm; 2: warm; 3: hot): in the dry season, all of the householders regarded their houses as warm-hot (PMV>2); in the rainy season, they are slightly cool (PMV = -1). Even though people feel slightly comfortable during morning, they still prefer to have the cooler thermal sensation as well as during the afternoon and evening shown by the thermal sensation preference less than zero (based on the preference range -1: cooler; 0: no change; 1: warmer).

Besides undertaking the measurement on post-tsunami houses, the thermal performance of several unaffected tsunami houses and Acehnese traditional houses were also measured to get the comparison. The results show that there was no significant difference of inside air temperature between the post-tsunami houses and the unaffected tsunami houses (except with the traditional Acehnese house). The inside air temperature values stand higher than the neutral temperature applicable in Indonesia. This confirms that the post-tsunami housing was built fully the same as the houses currently typical in Aceh, while the Acehnese traditional house was shown to have lower inside air temperature than the outside air temperature. It also shows that the mean inside temperature in the traditional Acehnese house is close to the comfort temperature proposed by Nicol and even meets the comfort temperature range proposed by Karyono, which may be more applicable, since his work was carried out in Indonesia.

# CHAPTER 7 – INDOOR THERMAL PERFORMANCE SIMULATED WITH DYNAMIC THERMAL MODELLING SOFTWARE TAS

## 7.1 Introduction

TAS building simulation software is utilized in this study analyzing the annual indoor thermal performance in five post tsunami house designs and the Acehnese traditional house. These houses are differentiated by building material, building form and layout. The annual thermal performance is shown by the software followed by PMV and PPD value (index predicting the thermal comfort of people working in a given environment).

This section begins by comparing the predicted indoor air temperature provided by TAS software with the measured data collected during the field trip. The comparison is carried out in order to validate the model constructed in the software. Further, the annual thermal performance in each house is simulated using the PMV and frequency macros run in MS excel. The performance shows the peak air temperatures and when they occur. TAS Ambiens, the dynamic thermal simulation is also carried out as the last phase. The indoor thermal performance is shown by dynamic flow of the dry bulb temperature, air velocity and relative humidity through the entire layout and a part of section of the houses.

The weather data utilised in the TAS building simulations is the data for the year 2009 provided by the meteorology office in Banda Aceh, Indonesia, and additional solar radiation data for latitude 0 from Environmental Design, CIBSE A (2006) was used.

Six houses modelled in TAS building simulation software are as follows:

a. Post tsunami house donated by World Vision
b. Post tsunami house donated by IOM
c. Post tsunami house donated Saudi Arabia
d. Post tsunami house donated by UPLINK
e. Post tsunami house donated by YBI
f. Acehnese traditional house

The details of building construction data were obtained by observation during the data collection. This may be slightly different from the house as designed by the house providers due to some changes made by individual householders.

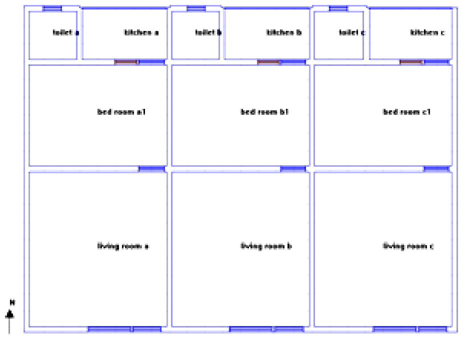
### 7.2 Comparison of the Measured and Predicted Indoor thermal performance

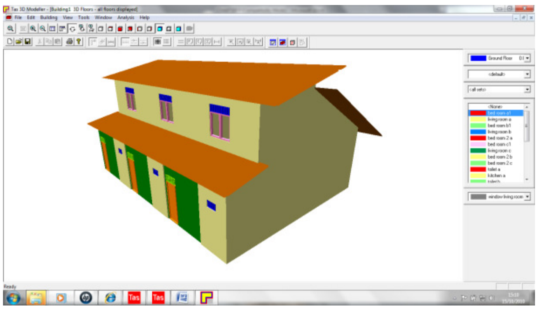
As a validating tool, this comparison is run by examining the difference between the measured and the predicted air temperature. During the field work, each of the houses was measured within two days but at different times of day due to the unavailability of the measuring equipment. Therefore the predicted data is only compared with the given measured data.

#### 7.2.1 Indoor Thermal Simulation of World Vision House

The World vision house simulated and measured in this section is the two storey house shown in the following figures:

a. 

b. 


c. 

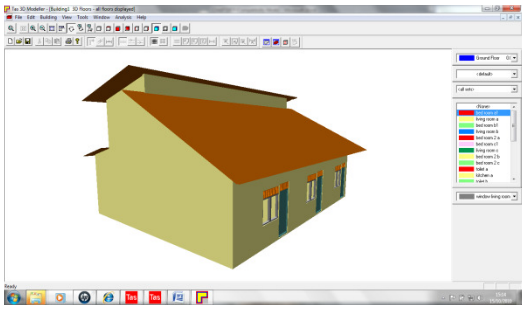
d. 

Figure 7.1 a. View of World Vision house, b. Ground floor layout, c. Rear side (model), and d. Front side (model)

This house type is semi detached house. Each house has a living room, a bedroom, a service area (kitchen and toilet) on the ground floor and a bedroom on the first floor. The details of this house are described in table 7.1.

Table 7.1 Building data of World Vision house

| Total house area | 42 $m^2$ | |
|---|---|---|
| House height | 6.625 m | |
| **Building constructions** | **Building materials** | **U value ($W/m^2K$)** |
| External Wall material | Batako (concrete brick work) (188.2 mm) | 1.95 |
| Internal Wall material | Ply wood (5 mm) | 3.33 |
| Ground floor material | cement floor (1255 mm) | 0.27 |
| Upper floor material | Timber floor (20 mm) | 2.5 |
| Ceiling material | Ply wood (5 mm) | 3.33 |
| Roof material | Zinc sheet (3 mm) | 3.8 |
| Door | Wooden door (50 mm) | 1.64 |
| Window | Single glass ( 6 mm) | 5.73 |

The window type is an awning which is roughly calculated to have an opening value of 0.25 for the purpose of the TAS simulation. This aperture is left open from 7 am-8 pm. There are other openings above the windows and doors with the assumed opening value of 0.75, which are open for 24 hours. The infiltration is assumed to be 0.5 ach for any air flow from the openings or the unintended cracks.

- **Result**

The simulation estimated the indoor thermal performance of the middle house for days 170-173, year 2009 (June, $19^{th}$-$22^{nd}$ 2009). Figure 7.2 shows that the measured peak indoor temperatures of the bed room and living room are by $1.6^0C$ and $2^0C$ respectively higher than the predicted values. The averages of the discrepancies in the both results are 0.7K and 0.3K respectively for bed room and living room. Apart from the discrepancy, the predicted and the measured data show a similar trend line which is also shown by the correlation coefficient of R= 0.94 or $R^2$ = 0.891 (figure 7.3). The World Vision house modelled in TAS seems to include materials with more thermal mass causing the lower temperature compared with the measured value of the real house.

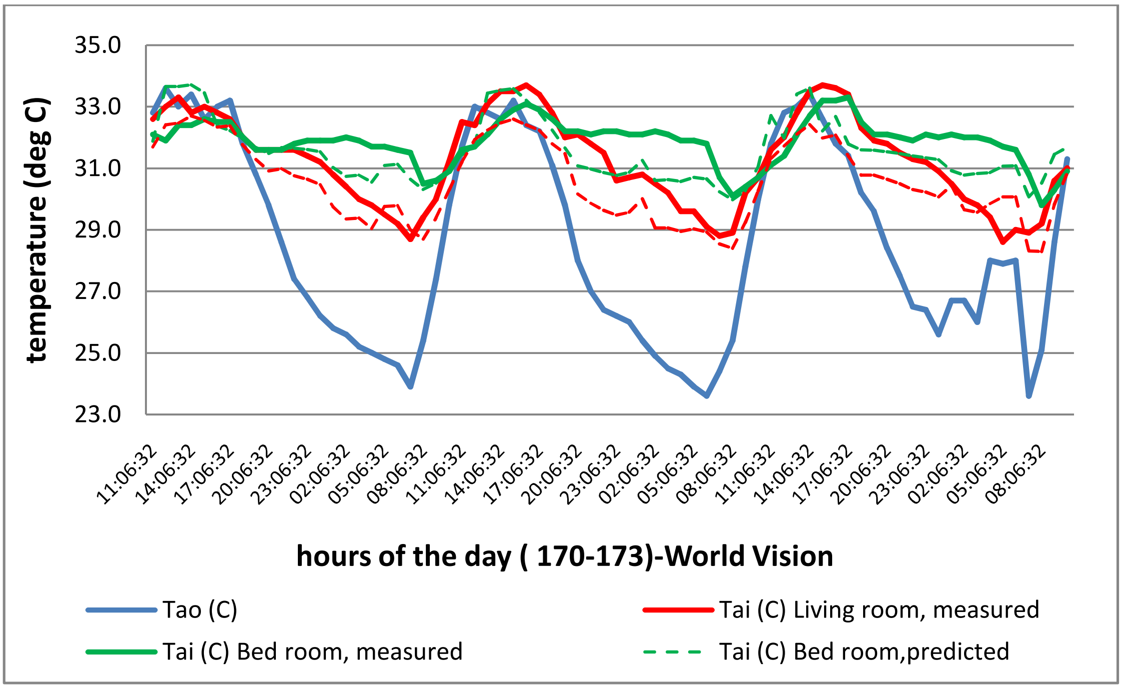



Figure 7.2 The predicted and measured inside air temperature of the World Vision house

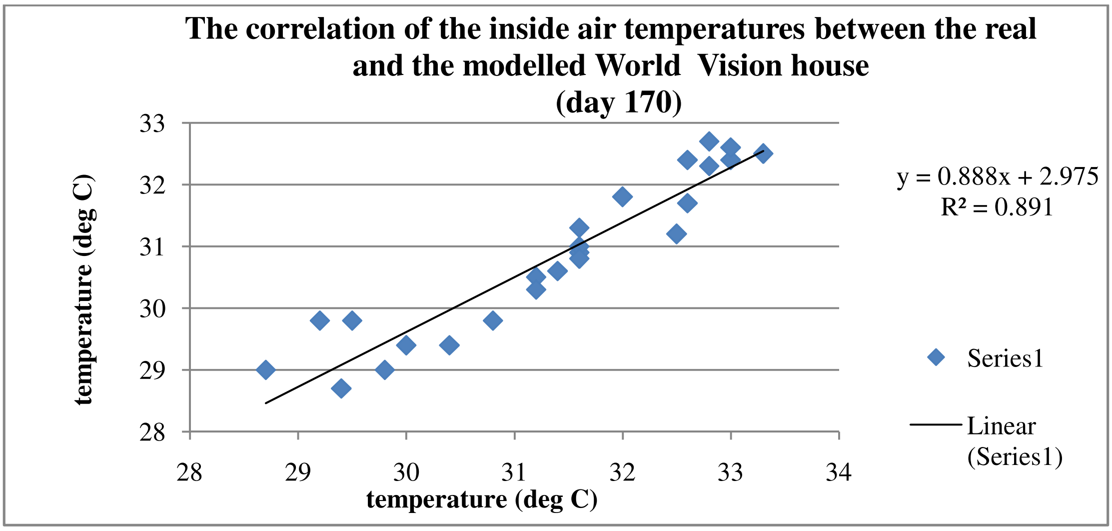



Figure 7.3 The correlation of the inside air temperatures between the real and the modelled World Vision house

### 7.2.2 Indoor Thermal Simulation of Saudi Arabia House

This is a detached house that has 3 bed rooms and one open living room united with the rear small kitchen. This house looks beautiful, and many people are happy with the house performance. The living room has a high ceiling at about 4.5 m, while the ceilings in other rooms are 3 meters high. Windows are designed in two types, namely awning types; and the ones shaded with horizontal fins. The opening value of the awning types are assumed to be 0.25, set up from 7am-8pm; with infiltration of 0.5ach for the whole building envelope, while the horizontal fins windows are assumed to be open for 24 hours.

a. b. c. d.

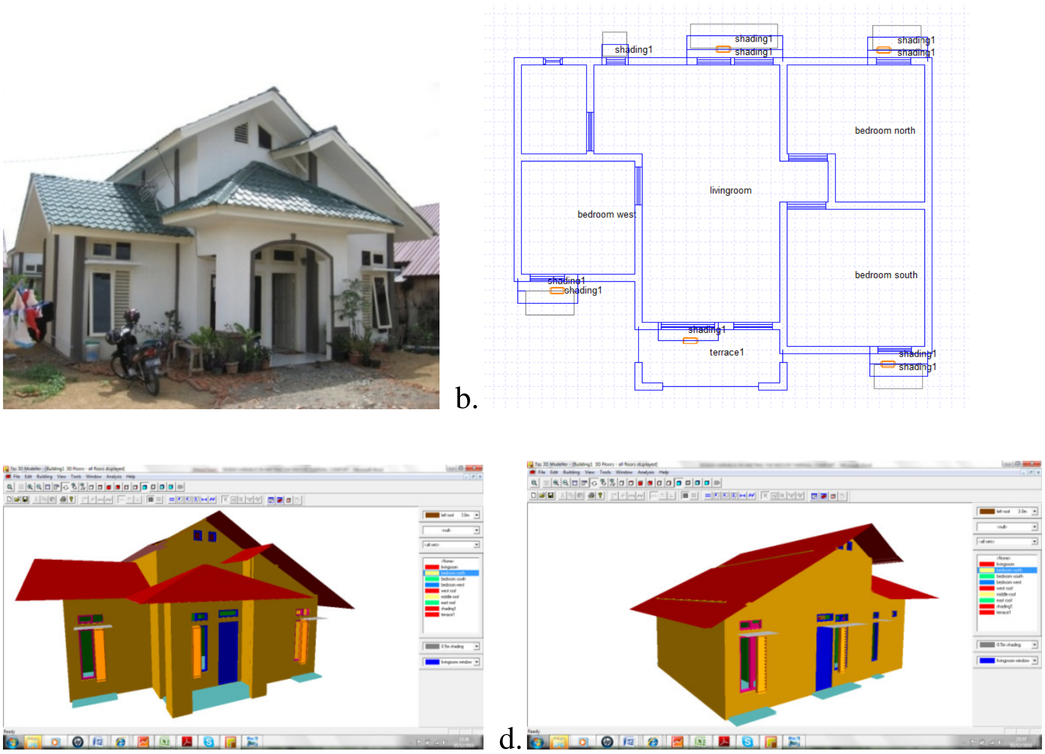



Figure 7.4 a. Real figure of Saudi Arabian house, b. Ground floor layout, c. Front side (model), and d. Rear side (model)

This house is built in heavy weight material and is recognised as a permanent house. The details of house constructions are described as follows:

Table 7.2 Building data of Saudi Arabian house

| | | |
|---|---|---|
| Total house area | 45 $m^2$ | |
| House height | 5.32 m | |
| **Building constructions** | **Building materials** | **U value ($W/m^2k$)** |
| External/ internal Wall material | Single brick work (123 mm) | 1.45 |
| Ground floor material | Ceramic floor | 0.49 |
| Ceiling material | Ply wood (5 mm) | 3.33 |
| Roof material | Aluminium sheet (3 mm) | 3.85 |
| Door | Wooden door (50 mm) | 1.64 |
| Window | Single glass ( 6 mm) | 5.73 |
| External shading | Flat concrete | 0.25 |

- **Result**

The living room and the rear bedroom facing north were measured and simulated. The result was a reduction in the peak outside temperature by $2^0$C, which is lower about $1^0$C than the predicted values. Meanwhile the minimum temperature occurring in the very early morning predicted by TAS is by $2\text{-}3^0$C lower than the measured values (figure 7.5). The largest discrepancies between the measured and the predicted values occurring in the absence of the sun may be due to the fin windows that were assumed to be open for 24 hours which could not be modelled precisely in TAS. However the R value of the both temperatures is quite close to 1 which is 0.96 or $R^2 = 0.927$ (figure 7.6).

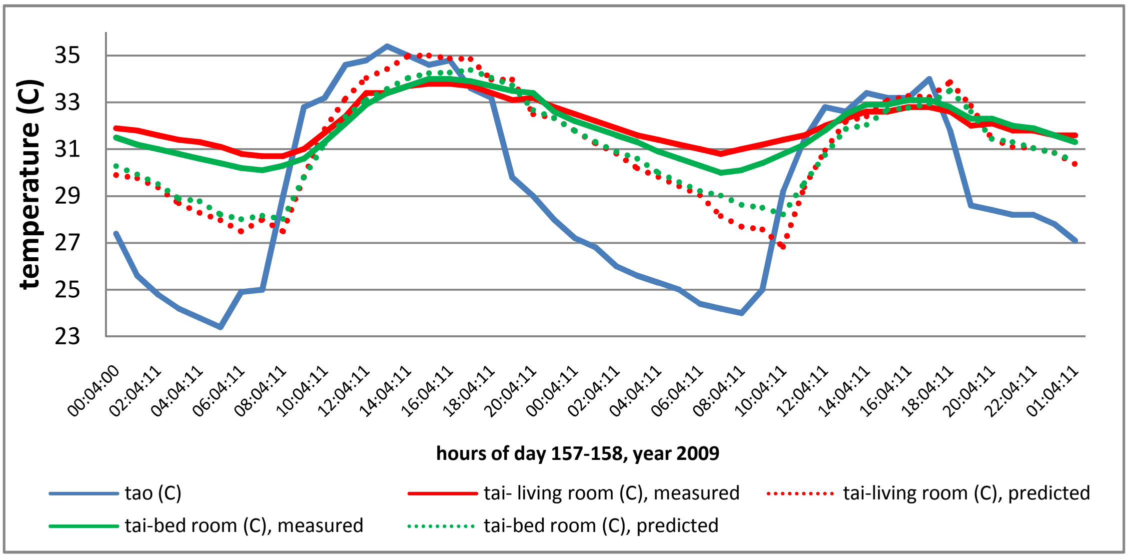



Figure 7.5 The predicted and the measured inside air temperature of Saudi Arabian house

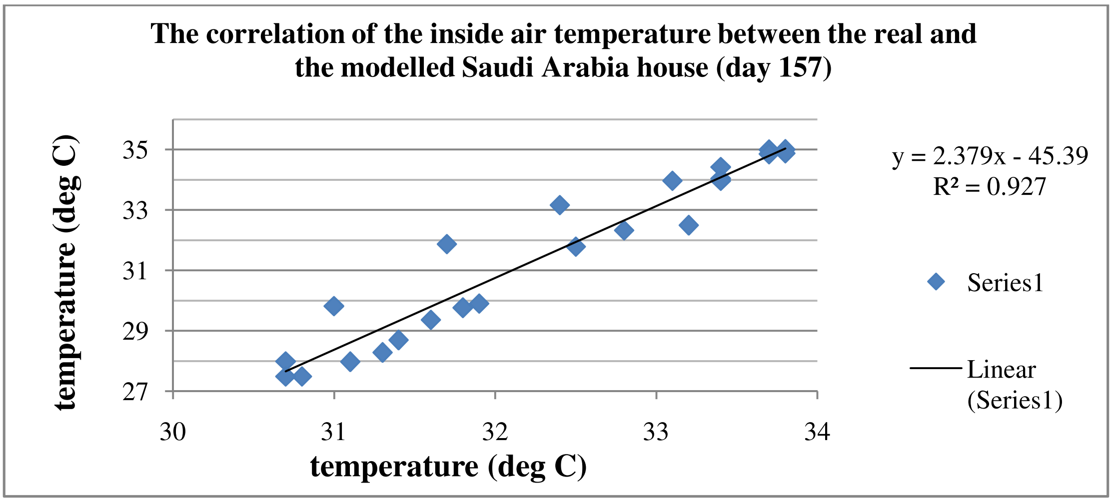



Figure 7.6 The correlation of the inside air temperature between the real and the modelled Saudi Arabia house

### 7.2.3 Indoor Thermal Simulation of IOM House

This 36m$^2$ detached house is constructed in light weight material. This is actually a temporary dwelling; nevertheless the house has been still occupied since it was built around four years ago. The dwelling is even rented to other people by the householders. The awning windows are assumed to have 0.25 opening value opened from 7am-6 pm. All the building envelopes are assumed to have 0.5 ach infiltration.

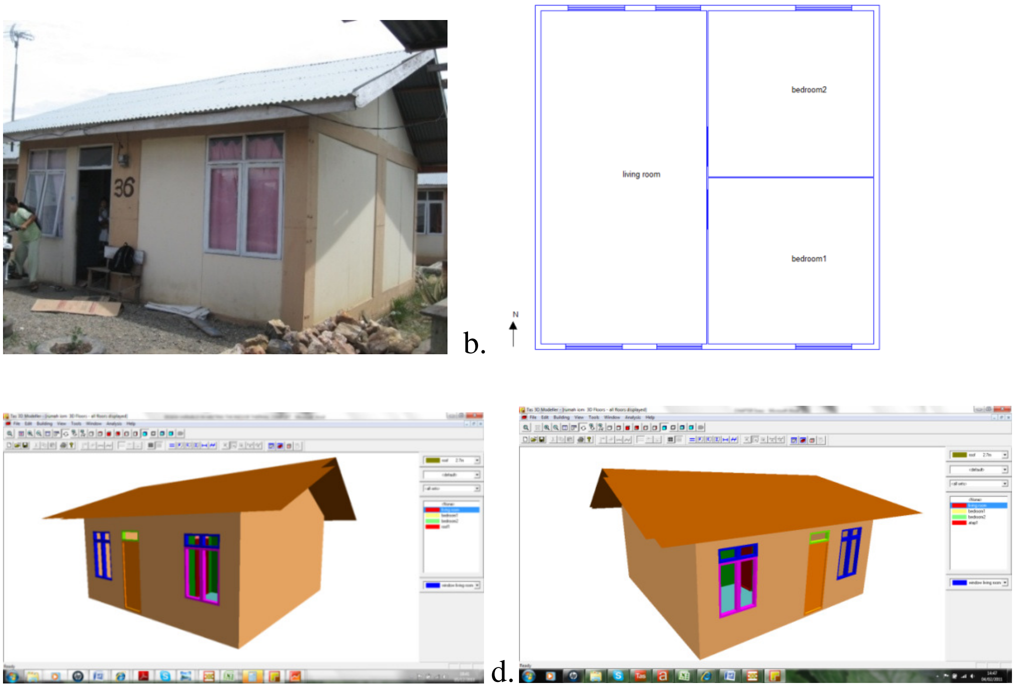



Figure 7.7 a. Real figure of IOM house, b. Ground floor layout, c. Rear side (model), and d. Front side (model)

The house construction is detailed in this table below:

Table 7.3 Building data of IOM house

| | | |
|---|---|---|
| Total house area | 36 m$^2$ | |
| House height | 4.2 m | |
| **Building constructions** | **Building materials** | **U value (W/m$^2$K)** |
| External/ internal Wall material | Calsiboard with cavity (60 mm) | 1.72 |
| Ground floor material | Cement floor (1255 mm) | 0.27 |
| Ceiling material | - | - |
| Roof material | Zinc sheet (3 mm) | 3.8 |
| Door | Wooden door (50 mm) | 1.64 |
| Window | Single glass ( 6 mm) | 5.73 |

- **Result**

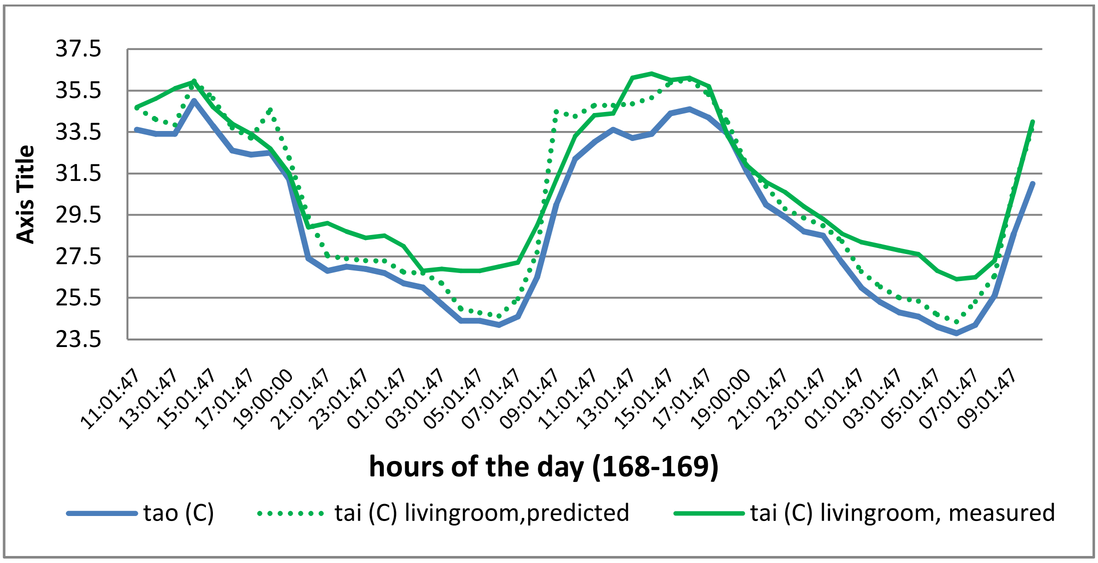



Figure 7. 8 The measured and the predicted inside air temperature of IOM house

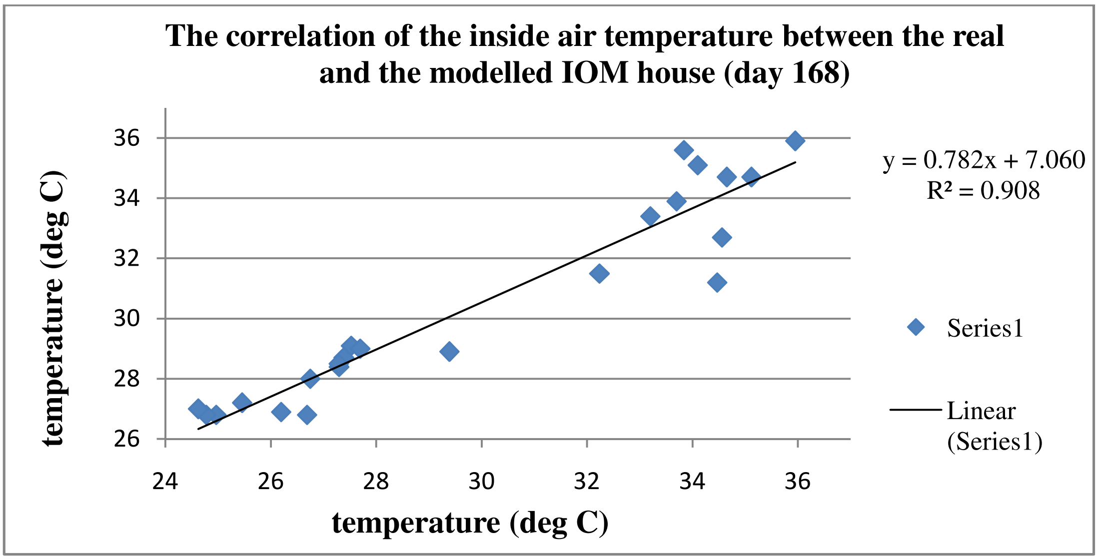



Figure 7.9 The correlation of the inside air temperature between the real and the modelled IOM house

Figure 7.8 above shows that the measured and the predicted inside air temperature in the IOM house are nearly similar shown by the R value of 0.95 or $R^2 = 0.908$ for both temperature (figure 7.9). The discrepancy occurs in the absence of the sun where the predicted value shows to be lower than the measured one. The peak temperatures of both are higher by $2^0$C than the peak outside air temperature. There is no time lag due to the very light building material.

### 7.2.4 Indoor Thermal Simulation of UPLINK House

The uplink house is a semi permanent house or half permanent house constructed from cemented brick and timber plank. The floor of the house is raised 1.8 meters from the ground. The awning windows are also estimated to have 0.25 opening value opened during the day. These windows are fitted with other smaller openings at the top assumed to have 0.75 opening value which are opened for 24 hours.

a. b. c. d.

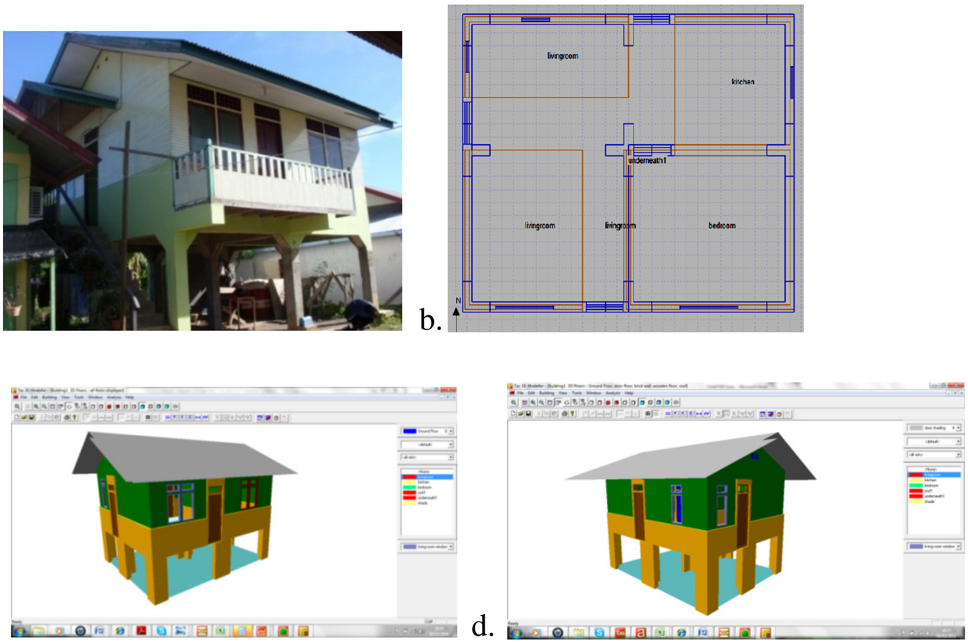



Figure 7.10 a. Real figure of Uplink house, b. Ground floor layout, c. Front side (model) and d. Rear side (model)

The house construction detail is as follows:

Table 7.4. Building data of Uplink house

| | | |
|---|---|---|
| Total house area | 36 $m^2$ | |
| House height | 6.4 m | |
| **Building constructions** | **Building materials** | **Internal U value ($W/m^2K$)** |
| Semi permanent Wall material | Double brick wall (233 mm) | 1.5 |
| | Timber plank (20 mm) | 2.5 |
| Ground floor material | Concrete floor (1250 mm) | 0.276 |
| Upper floor material | Timber floor (50 mm) | 1.65 |
| Ceiling material | Ply wood (10 mm) | 2.8 |
| Roof material | Zinc sheet (3 mm) | 3.8 |
| Door | Wooden door (50 mm) | 1.64 |
| Window | Single glass ( 6 mm) | 5.73 |

- **Result**

The peak predicted air temperature is 2$^0$C higher than the measured values. The trend of these both indoor temperatures is generally higher than the outside air temperature as shown in figure 7.11 The high inside air temperature may be due to the raised floor design that is considered by TAS to have more surfaces exposed to the air by including the under floor that is indirectly heated by the ground radiation causing the higher air inside air temperature compared with the grounded house. The slight discrepancies occurring during the day and in the absence of the sun may be due to the lighter building materials used in the model that created values close to the outside value. However the R value of the both temperature is close to 1 which is 0.94 or $R^2 = 0.892$ which shows a good correlation (figure 7.12).

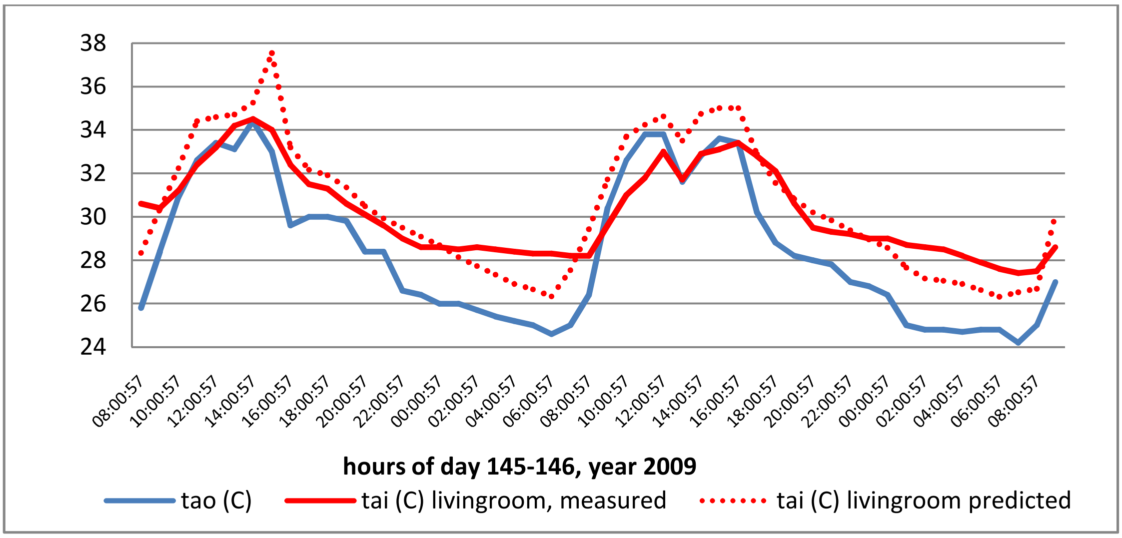



Figure 7.11. The measured and the predicted inside air temperature of Uplink house

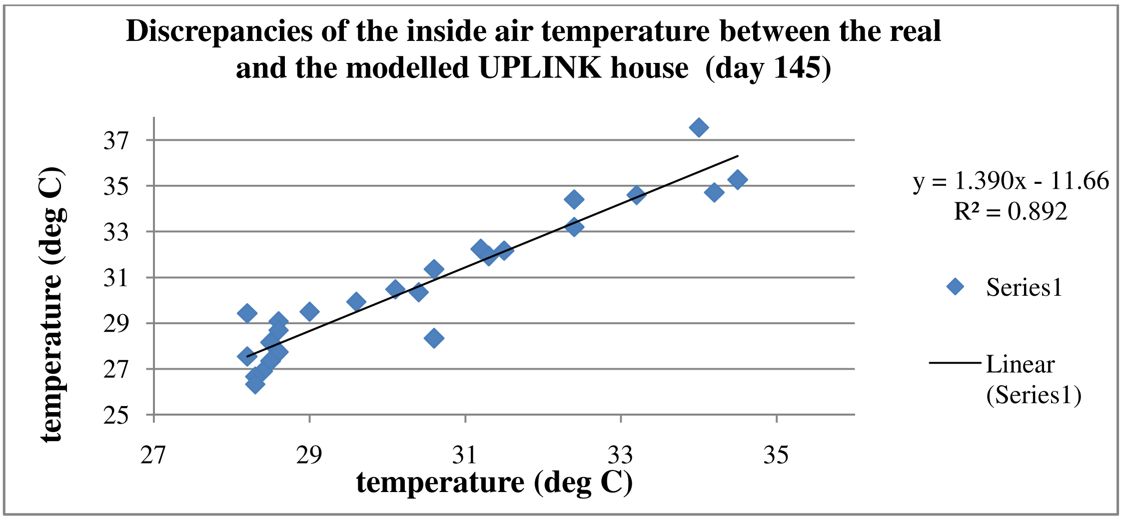



Figure 7.12 The correlation of the inside air temperature between the real and the modelled UPLINK house

### 7.2.5 Indoor Thermal Simulation of YBI House

Another type of semi permanent house mostly built by house donors is the grounded floor one as shown in figure 7.13. This house with the same building materials as the house built by UPLINK has the ventilations above the window that are open for 24 hours. While the windows are assumed to be open 50% from 7am to 6pm.

Figure 7.14 shows that the predicted temperature is about $1^0$C higher than the measured one. The higher inside air temperature of the measured and the modelled house than the outside value may be due to the thermal characteristics of the wood that is part of light weight materials. There are the great discrepancies between the measured and the modelled house occurring in the absence of the sun. This may be the result of the modelled ventilation which is open for 24 hours creating the inside air temperature close to the outside value. This correlation of the two cases is shown by R=0.89 or $R^2$ = 0.786 (figure 7.15).

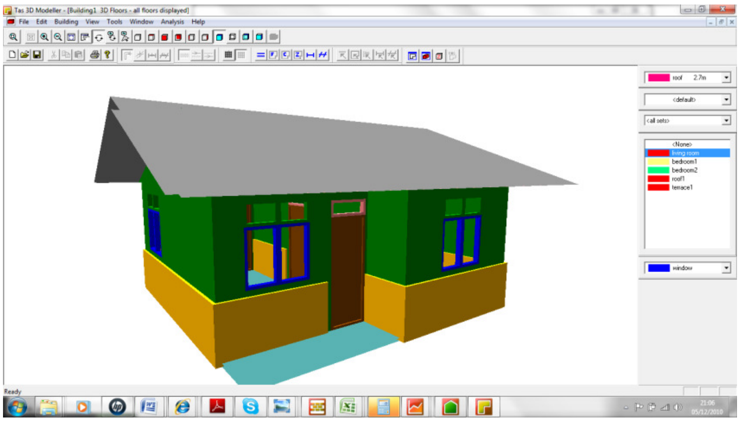


Figure 7.13 YBI house

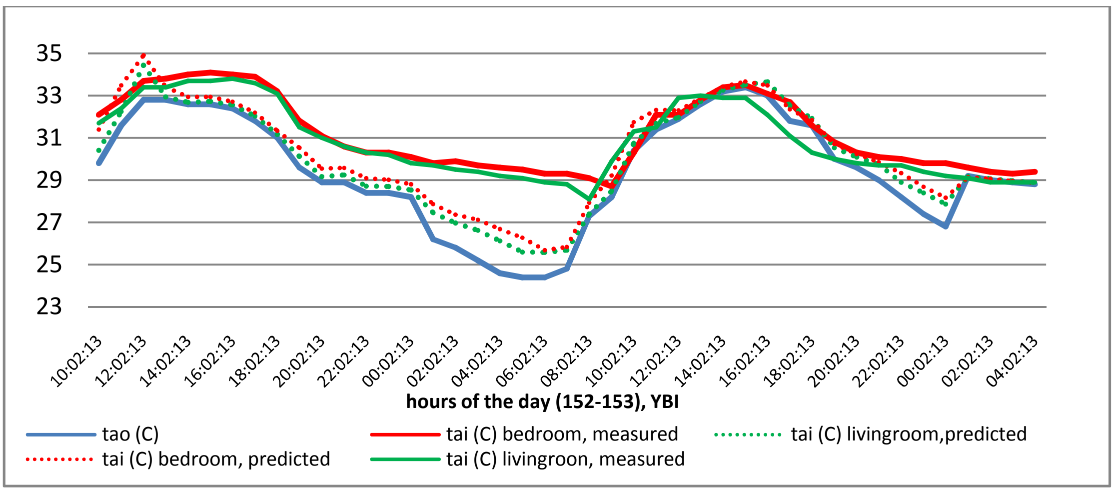



Figure 7.14 The measured and the predicted inside air temperature of YBI house

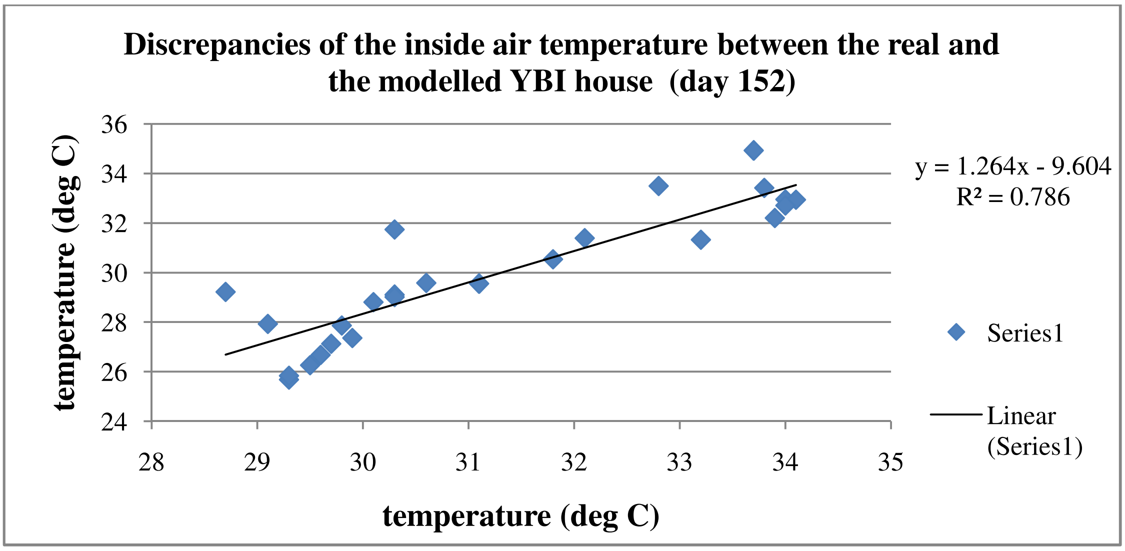



Figure 7.15 The correlation of the inside air temperature between the real and the modelled YBI house

### 7.2.6 Acehnese Traditional House

In this section the Acehnese traditional house is simulated (figure 7.16). This raised floor house has many windows made from wood which are fully open during the day. The absence of glass window panes sheet allows the air to flow through the windows freely. Hence in the simulation, the opening value is assumed to be 1 opened from 7 am to 6 pm. The infiltration is assumed to be 0.5 ach applied to all of the building envelope.

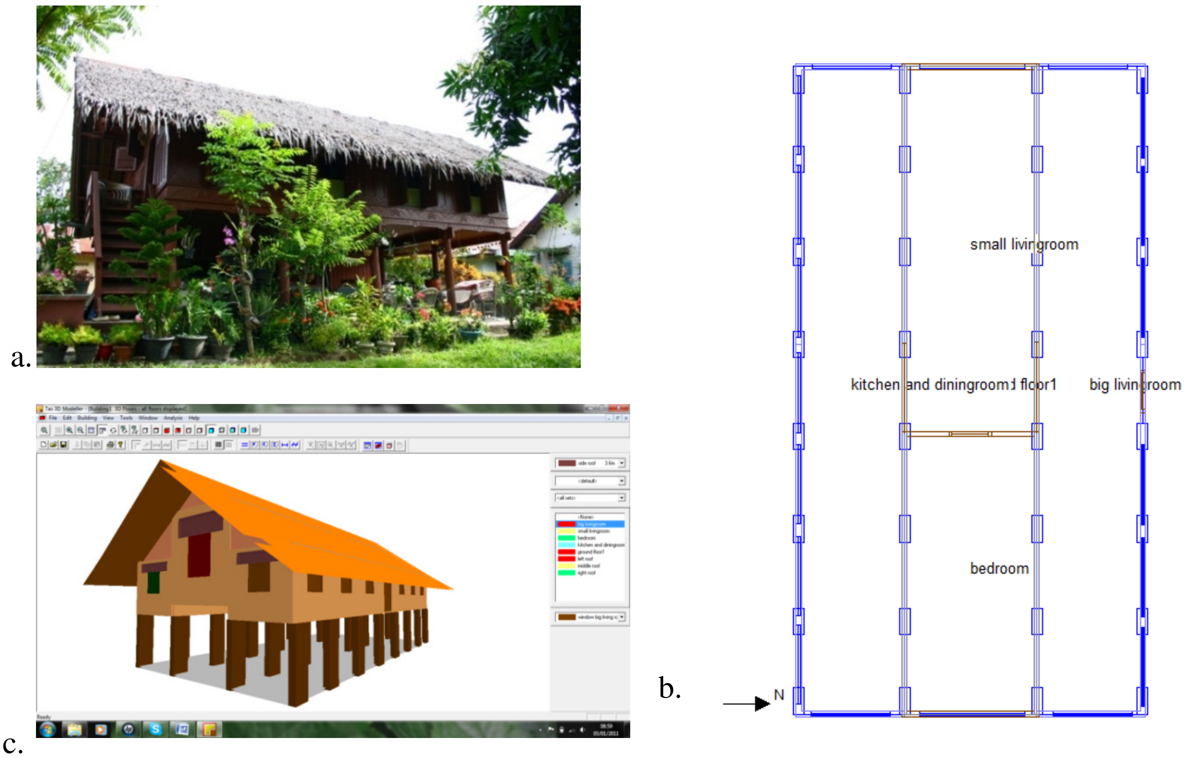



Figure 7.16 a. Real figure of Acehnese house, b. First floor layout, c. Front side (model)

This traditional house is constructed from the following building materials:

Table 7.5 Building data of Acehnese traditional house

| | | |
|---|---|---|
| Total house area | 77.62 $m^2$ | |
| House height | 5.9 m | |
| **Building constructions** | **Building materials** | **U value ($W/m^2K$)** |
| External/ internal  Wall material | Teak  (50 mm) | 1.607 |
| Ground floor material | Teak  (50 mm) | 1.607 |
| Ceiling material | softwood (16 mm) | 2.672 |
| Roof material | Thatch (300 mm) | 0.22 |
| Door | Soft wood (50 mm) | 1.64 |
| Window | Soft wood (50 mm) | 1.64 |

- **Result**

The simulation result is compared with the data from the corresponding field measurement carried out from 9th June 2009 to 3rd July 2009. In figure 7.17 we see that predicted inside temperatures are quite close to the outside value. The different air temperature between the predicted and the measured one is $\pm$2-4K for both the peak value during the day and the lowest value during the night or the very early morning. This significant difference shown by R= 0.86 or $R^2$ = 0.751 (figure 7.18) may be the result of the outside shadow of many trees around the house which may reduce the measured inside air temperature substantially.

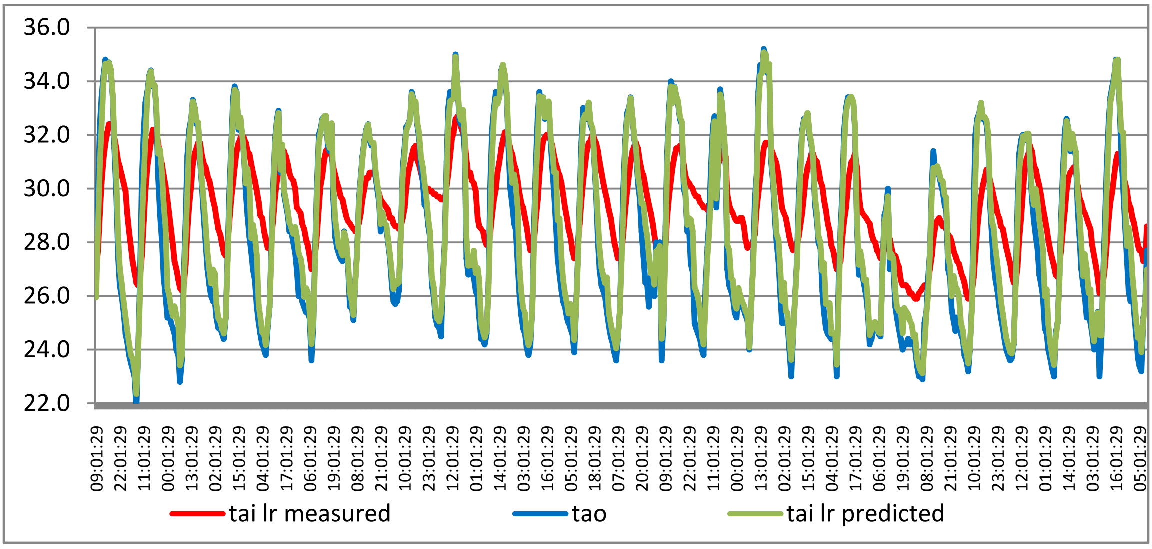



Figure 7.17 The measured and the predicted inside air temperature of Acehnese traditional house (day 160-184, year 2009)

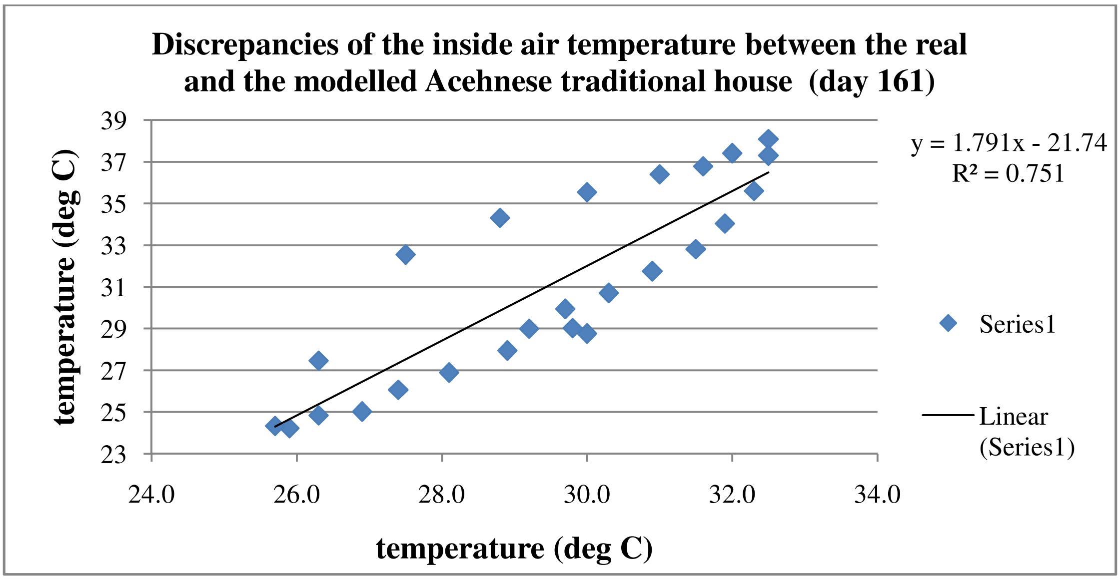



Figure 7.18 The correlation of the inside air temperature between the real and the modelled Acehnese traditional house

From these six models, except for the Acehnese traditional house, we see that the indoor temperatures simulated by TAS software are $\pm 1^0$-$2^0$C different from the measured ones, while the difference in the Acehnese traditional house is $\pm 2^0$-$4^0$C.These discrepancies may be due to:

1. The global and diffuse solar radiation data of year 2009 or during the field trip are not available either from the weather measuring tool or the meteorology office. Therefore, the solar data of latitude 0 from Environmental Design, Cibse A (2006) are utilised to cover this unavailability.
2. The uncertainties concerning the thermal properties of the existing materials which may lead to higher or lower prediction of solar penetration in the model, resulting both the higher and the lower prediction of the indoor air temperature and indoor heat gain.
3. The building materials used in TAS simulation may not be exactly the same as the ones used in the real house. The materials applied are inserted from the available construction data in TAS software that are assumed to have the same characters and thermal properties.
4. TAS predicts the inside air temperature in the Acehnese traditional house to be as almost high as the outside air temperature which is higher about $\pm 2^0$-$4^0$C than the measured inside air temperature. Apart from the above main reasons, it was not possible to simulate in TAS the effect of the trees surrounding the house, which can cause a lowering in temperature. Therefore the predicted temperature is higher than the measured one.

5. The daily behaviour of the house occupants in dealing with the apertures are quite various. Some open the window only during the day and close the ventilation above the windows to protect against the rain while others leave the ventilations open for 24 hours. Since the habits were not recorded hourly, TAS only applied the window to be open during the day, while ventilations are open for 24 hours as it is supposed to be. This may explain the large discrepancy between the real and the modelled house during the absence of the sun, where the inside air temperatures in the model are lower and closer to the outside air temperature.

### 7.3 Annual Indoor Thermal Performance of Post Tsunami Housing

This annual indoor thermal performance is assessed by considering the TAS validation process in the previous chapter. The result may be different by about $\pm$1-2 $^0$C from reality as shown in the validation conclusion. The annual indoor thermal performance is simulated by TAS software by applying the following PMV parameters:

- **Metabolic rate**: 1.2 met (this value applies to light activities, such as standing and relaxing, normally done by the occupants throughout the day).
- **External work**: 0 W/m$^2$ (no external work is applied in this simulation)
- **Air velocities**, Min: 0.06 m/s; max: 0.31 (these values are the inside air velocity concluded from the field trip measurement conducted in 20 houses).
- **Clothing values**, min: 0.29 clo; max: 0.38 clo (these values were obtained from the observation during the field trip, that people normally wear very light clothing at home).

Once a simulation has been run and results file (TSD) are created, MS Excel macros is used to extract the result. In this study only the Frequency and PMV macros are used. The frequency macro is used to examine both the frequency and cumulative frequency of temperatures and humidities of selected zones in the model during a specified time period, while PMV macro is used for calculating PMV and PPD of the model.

The selected macro program assesses the following parameters:

a. Indoor air temperature

The indoor air temperature discussed in this chapter is the performance of annual inside air temperature determined by the frequency macro in average difference between internal and external; and the peak of air temperature of each simulated zone. The values are specified according to the hour and day of the year.

b. PMV and PPD

PMV macro predicts the percentage of PMV outside and inside the comfort range. The comfort range is $-1 < PMV < 1$. The highest and the lowest of PMV and PPD values are also specified in hour of the year.

Another parameter that is shown in this study is TAS Ambiens. This is not run in MS Excel macros but in Tas Ambiens File (TAI).

c. Tas Ambiens

Ambiens is a 2D computational fluid dynamics (CFD) program, specifically designed to model air flow and temperatures in buildings. In this study the result of dry bulb, air speed and humidity are shown.

### 7.3.1 World Vision Post Tsunami House

a. Air temperature

The simulation assesses three single houses arranged in semi detached house type (figure 7.1). Table 7.6 shows that all the upper floors (bedroom 2a, 2b, and 2c) reach their peak temperature ($36.9^0$, $37.5^0$C, $37.4^0$C respectively) on day 207 that is July, 26th at 3pm. Bedroom 2b which is in the middle of the row suffers the highest inside air temperature among all of the zones that is $37.5^0$C.

Table 7.6 Inside air temperature performance of World Vision house

| Zone | Average Difference between Internal and External (°C) | Peak (°C) | Day of Peak | Hour of Peak |
|---|---|---|---|---|
| External - Banda Aceh 0 latitude | N/A | 36.3 | 215 | 14 |
| Bed room a1 | 2.6 | 33.9 | 145 | 14 |
| Living room a | 2.4 | 34.0 | 215 | 16 |
| Bed room b1 | 2.9 | 34.3 | 208 | 13 |
| Living room b | 2.7 | 34.2 | 215 | 14 |
| Bed room 2 a | 3.5 | 37.0 | 207 | 15 |
| Bed room c1 | 2.8 | 34.4 | 208 | 13 |
| Living room c | 2.6 | 34.4 | 215 | 16 |
| Bed room 2 b | 3.8 | 37.5 | 207 | 15 |
| Bed room 2 c | 3.6 | 37.4 | 207 | 15 |

All living rooms (living room a, b, c) which are located on the ground floor suffer their highest temperature on August 3rd, on the same day when the outside air temperature reaches its peak temperature. Among these three living rooms, living room c located on the east side reaches the highest temperature that is $34.4^0$C.

The single house with initial b located in the middle row has the largest average temperature difference, that is, $3.1^0$ C. Yet, it is not too significantly different compared with other single houses designated a and c in the same row which are $2.8^0$ C and $2.9^0$ C respectively.

b. PMV and PPD

Based on PMV and PPD calculations run by TAS, in average, 81.7% of thermal sensations during the year are out of the comfort range (table 7.7). It means that only about 18.3% of time where the PMV values are predicted to be voted by occupants as comfortable ranged in slightly warm to cool (-1<PMV<1). The middle single house, zone initialized in b is the worst in terms of thermal sensation, and is followed by the east and the west side houses respectively.

Table 7.7 PMV performances in World vision house

| Zone name | *Outside range* | *-1 < PMV < 1* | *-0.75 < PMV < 0.75* | *-0.5 < PMV < 0.5* |
|---|---|---|---|---|
| Bed room a1 | 76.95 | 23.05 | 8.60 | 3.15 |
| Living room a | 72.25 | 27.75 | 12.63 | 4.57 |
| Bed room b1 | 84.81 | 15.19 | 4.97 | 2.11 |
| Living room b | 79.94 | 20.06 | 7.25 | 1.88 |
| Bed room 2 a | 87.44 | 12.56 | 5.34 | 1.80 |
| Bed room c1 | 80.53 | 19.47 | 7.28 | 2.49 |
| Living room c | 73.96 | 26.04 | 12.27 | 4.03 |
| Bed room 2 b | 92.89 | 7.11 | 2.50 | 0.92 |
| Bed room 2 c | 87.63 | 12.37 | 5.15 | 1.66 |
| Average | 81.82 | 18.18 | 7.33 | 2.51 |

The Predicted Percentage Dissatisfied (PPD) Index in this house consequently follows the PMV value. The higher PPD values (50% - 100%) mostly occur in the upper rooms (bed room 2a, bed room 2b, and bed room 2c) of every house in the row (figure 7.19).

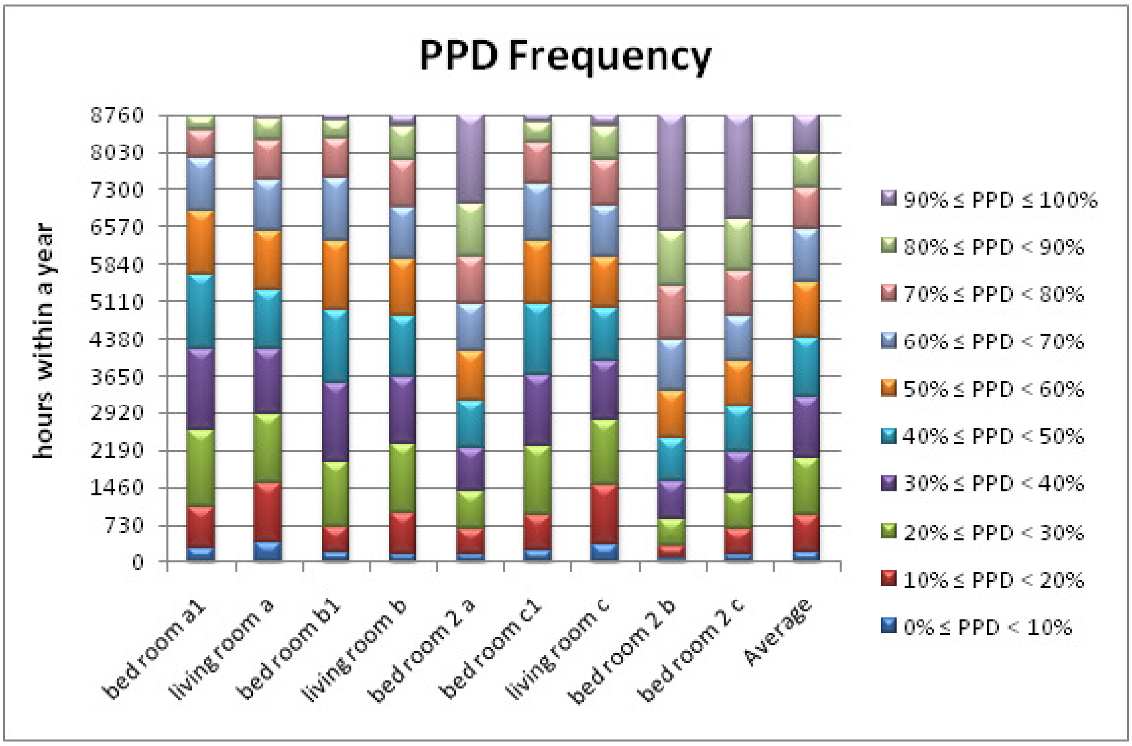



Figure 7.19 PPD performances in World Vision house

d. TAS Ambiens

In this case the TAS ambiens is run by using the data of the measurement conducted on $12^{th}$ June 2009 at 10.10 am in the World Vision house. The following data are applied:

Table 7.8 Surface temperature of World Vision house

| Temperature of living room surface ($^0$C) | | | | | Temperature of bed room surface ($^0$C) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wall | Ceiling | Floor | Glass | Door | Wall | Ceiling | Floor | Glass | Door |
| 30.1 | 36.3 | 31.2 | 34.3 | 34.4. | 31.5 | 31.8 | 31.5 | 31.8 | 31.9 |

No measurement in the kitchen was carried out. Therefore the surface temperature in this room is estimated to be close to the value of the adjacent room.

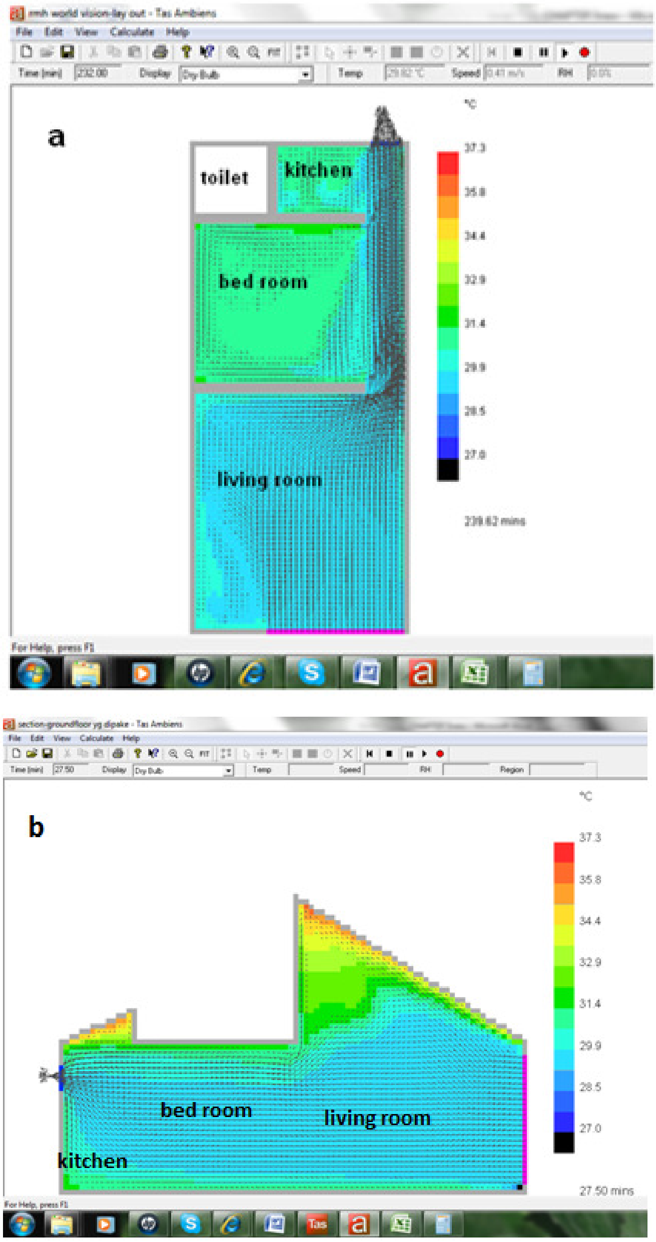



Figure 7.20 The dry bulb temperature flow on the ground floor (a), and through the section (b) of the World Vision house

The inlet coloured in pink applies the following outside data Tao: 29.8$^0$C, Rho: 68%, Av: 2.05 m/s. Figure 7.20 shows that during morning the temperature in the living room downward the ground floor is quite close to the outside temperature, that is around 29.9$^0$C. The bedroom is shown to have a higher temperature, up to 32.9$^0$C. The closer to the ceiling the higher temperature becomes, gradually moving from 31.4$^0$C, 32.9$^0$C, 34.4$^0$C and 35.8$^0$C close to the ceiling temperature.

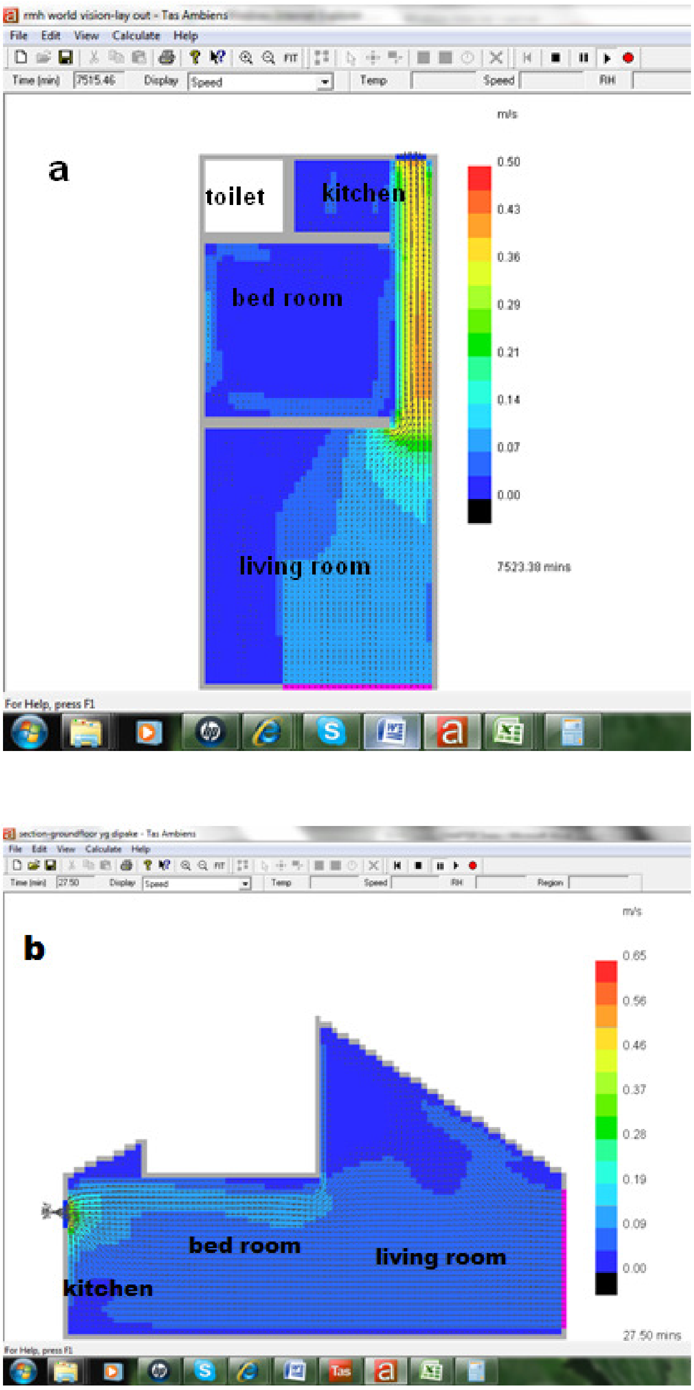



Figure 7.21 The air speed on the ground floor (a), and through the section (b) of the World Vision house

The outside air speed which is about 2.05 m/s is reduced significantly when entering the house. In the bedroom the air speed is close to zero, since the air appears to flow straight to the kitchen which has the only outlet to outside. The corridor area is the only area with a reasonable air flow, with an air speed of 0.3 to 0.4m/s (figure 7.21).

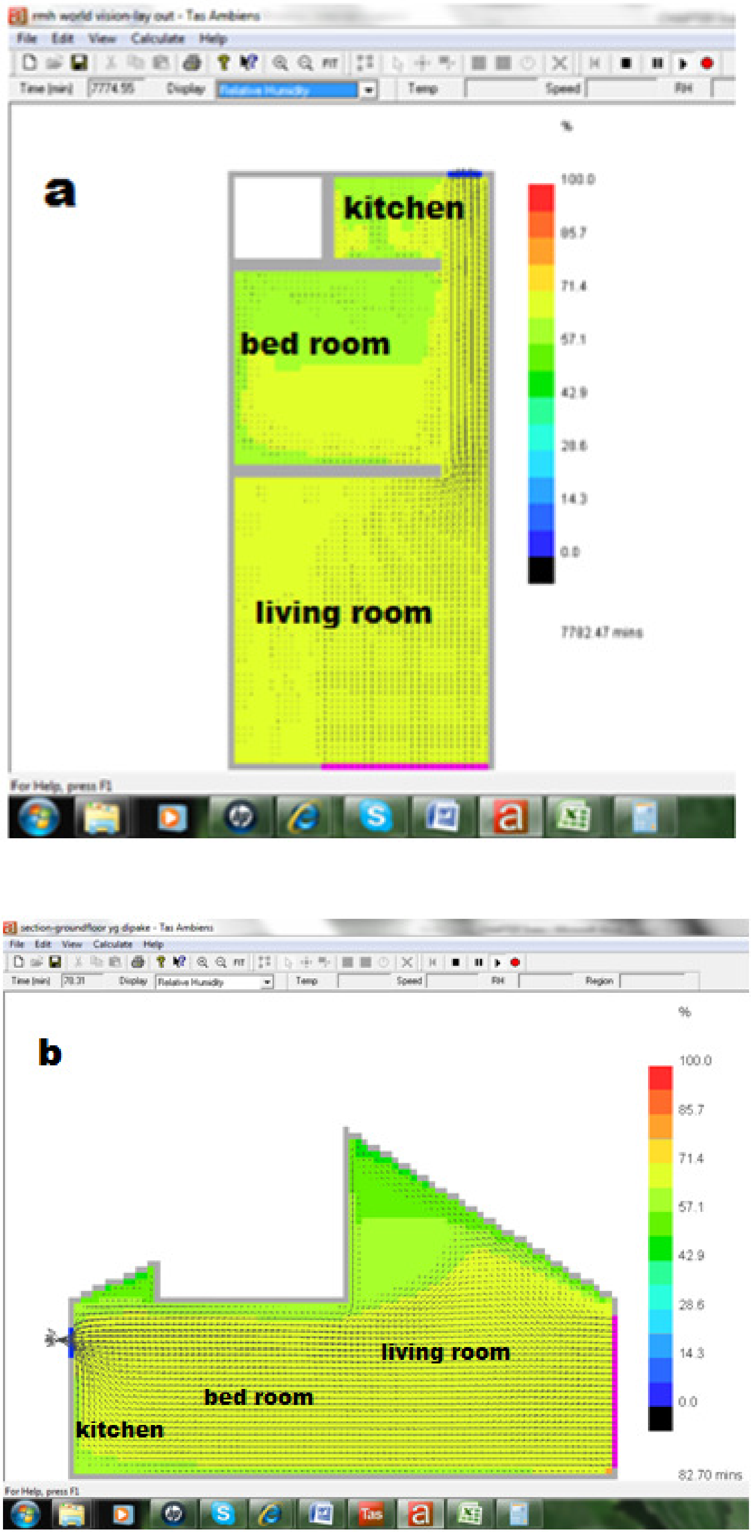



Figure 7.22 The relative humidity flow on the ground floor (a), and through the section (b) of the World Vision house

Figure 7.22 shows that the inside Relative Humidity (RH) appears to be similar to the outside value which is around 68%. The bedroom that has the higher temperature conversely has the lower RH value. It also happens in the ceiling zone which is even lower down to 42.9% RH.

### 7.3.2 Saudi Arabia Post Tsunami House

This simulation assesses the living room and the bedroom of the house donated by Saudi Arabia (figure 7.4). Table 7.9 shows that the highest peak temperature, $36.6^0$C, happens in July, 26th at 3pm in living room zone. Only the bedroom facing west reaches the peak temperature on the same day as the outside temperature does, that is on August 3rd. The average temperature difference between inside and outside in all zones is $1.9^0$C.

a. Indoor air temperature

Table 7.9 inside air temperature performance of Saudi Arabia house

| Zone | Average Difference between Internal and External (°C) | Peak (°C) | Day of Peak | Hour of Peak |
|---|---|---|---|---|
| External - Banda Aceh 0 latitude | N/A | 36.3 | 215 | 14 |
| Livingroom | 1.9 | 36.6 | 207 | 15 |
| Bedroom north | 2.1 | 35.4 | 207 | 16 |
| Bedroom south | 2.0 | 35.1 | 207 | 16 |
| Bedroom west | 1.8 | 34.9 | 215 | 16 |

b. PMV and PPD

On average, there are about 44.9% of hours within a year where the PMV value in this house model is in the comfort zone that is $-1 < PMV < 1$. The PPD value is predicted to be less than 30% in those comfortable hours.

Table 7.10 PMV performances of Saudi Arabia house

| Zone name | *Outside range* | *-1 < PMV < 1* | *-0.75 < PMV < 0.75* | *-0.5 < PMV < 0.5* |
|---|---|---|---|---|
| Living room | 54.84 | 45.16 | 35.74 | 25.72 |
| Bedroom north | 56.08 | 43.92 | 32.09 | 20.72 |
| Bedroom south | 55.90 | 44.10 | 34.05 | 23.38 |
| Bedroom west | 53.41 | 46.59 | 36.13 | 25.51 |
| Average | 55.06 | 44.94 | 34.50 | 23.83 |

The remaining 55% of hours are predicted to be out of the comfortable zone ($PMV \geq 1$ ) regarded by 30%-100% of PPD value. It means that there are about 4,823 hours within a year where people are dissatisfied with the indoor thermal performance in this house model (figure 7.23).

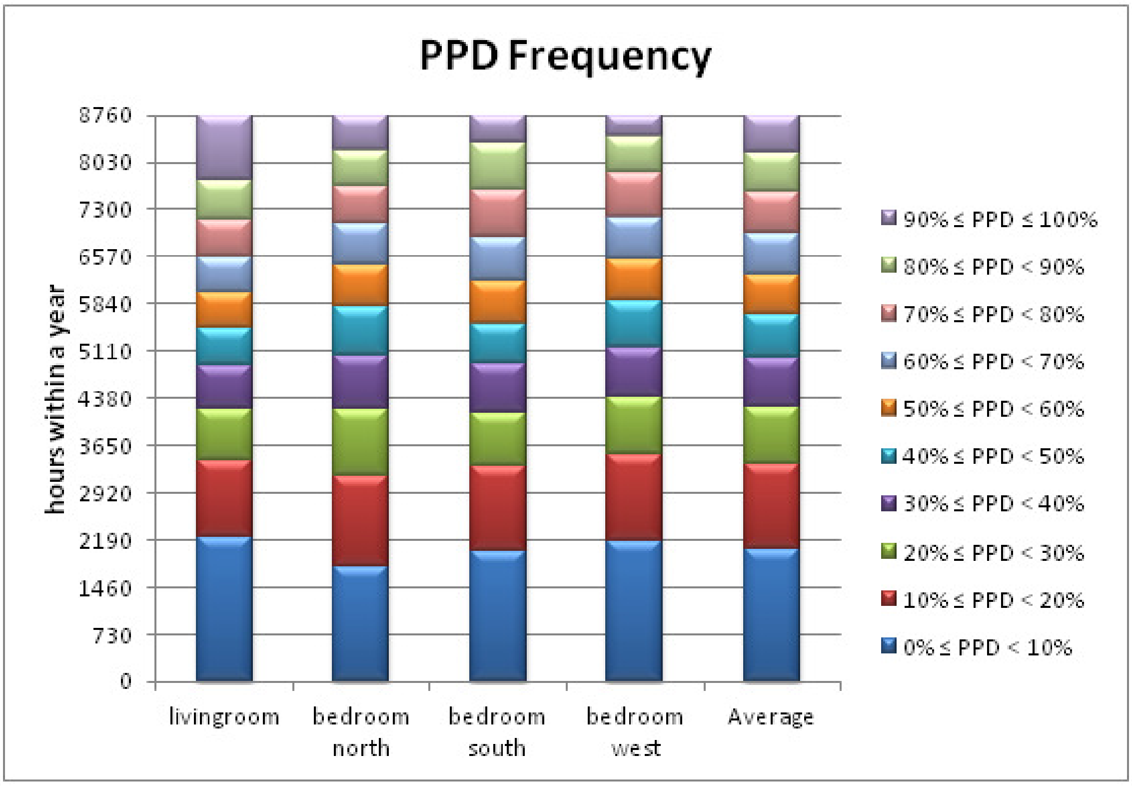



Figure 7.23 PPD performances in Saudi Arabia house

c. TAS Ambien

In this house, TAS Ambiens uses the data from the measurement carried out on 3rd June 2009 at 3 pm. The following data are applied.

Table 7.11 Surface temperature of Saudi Arabia house

| Temperature of living room surface ($^0$C) | | | | | Temperature of north bed room surface ($^0$C) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wall | Ceiling | Floor | Glass | Door | Wall | Ceiling | Floor | Glass | Door |
| 34.1 | 36.3 | 33.4 | 35.8 | 34.6 | 34.1 | 36.2 | 33 | 38.1 | 34.2 |

The surface temperature of the other rooms that are not mentioned on the above table is roughly estimated to be close to value of the nearby rooms.

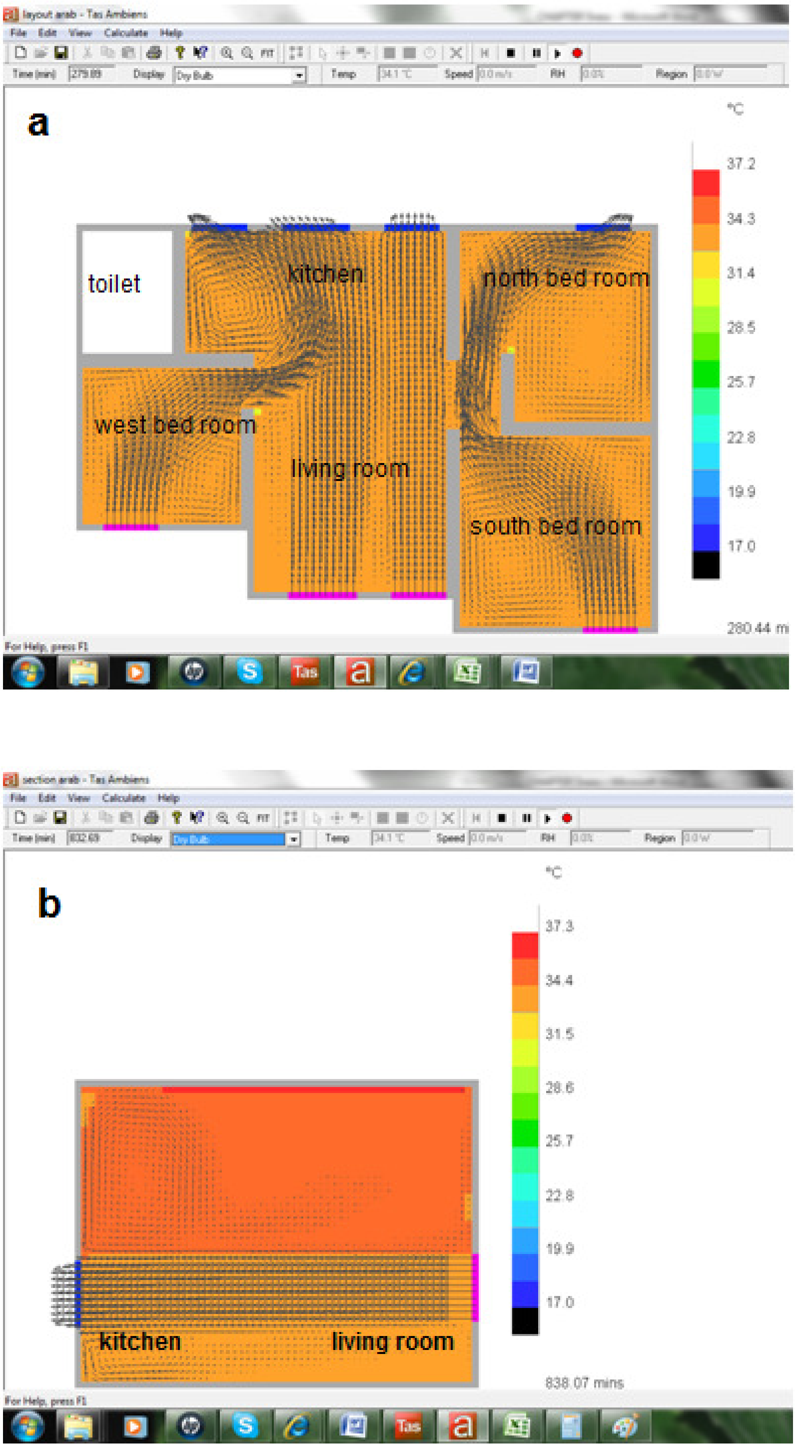



Figure 7.24 The air temperature on the ground floor (a), and through the section (b) of Saudi Arabia house

The pink inlet applies the following data tao: 34.2$^0$C, Rho: 46%, Av: 5.14 m/s. Figure 7.24 shows that the high outside temperature flows evenly throughout the layout during afternoon creating the inside air temperature as high as the outside value.

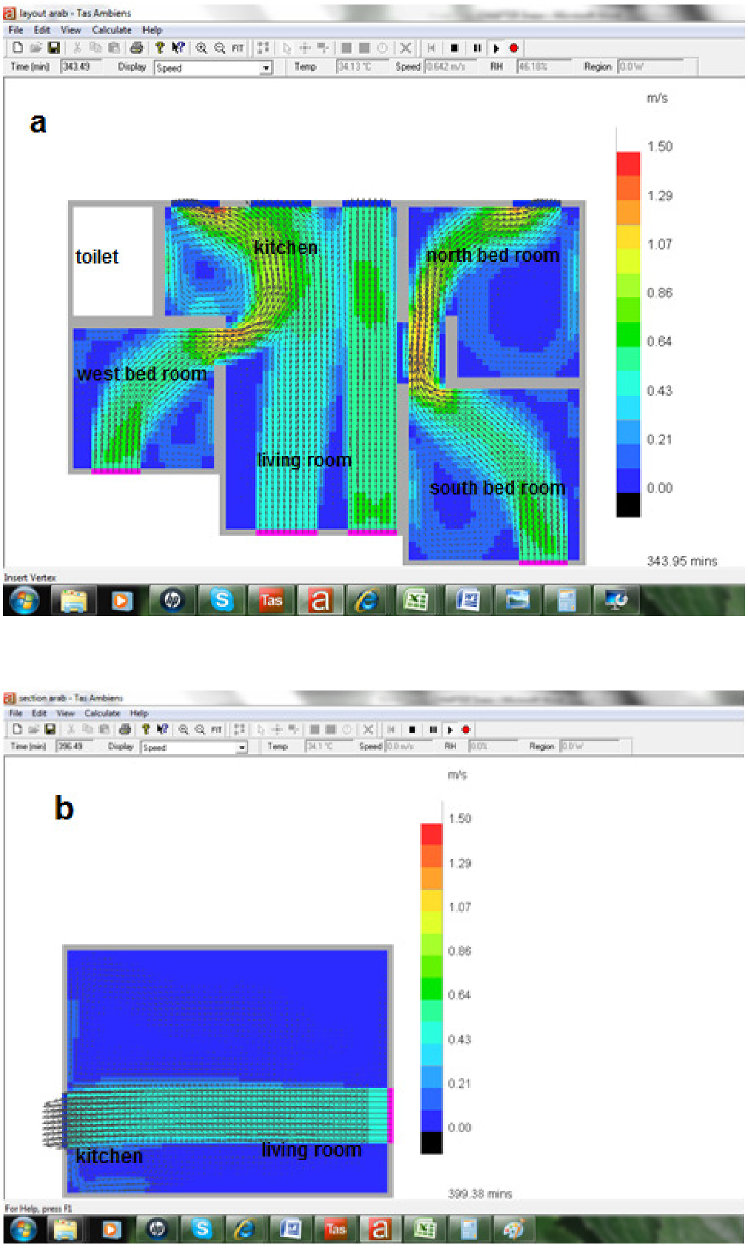
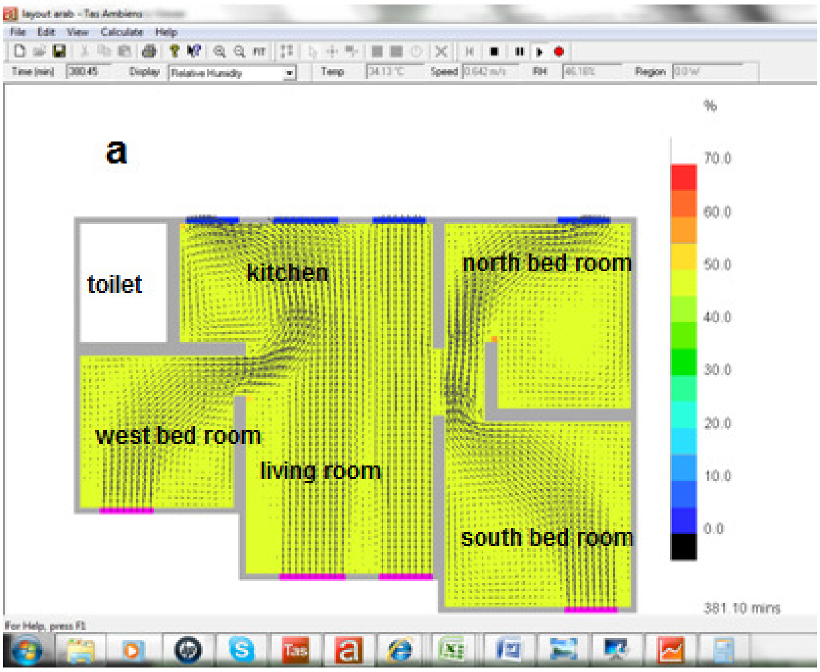



Figure 7.25 The air speed on the ground floor (a), and through the section (b) of the Saudi Arabia house

The air which is assumed to come in from south flows to all rooms. Nevertheless there are still some areas remaining with nearly zero air speed which happens in some areas in the bedrooms facing south and north. The living room and kitchen are the areas where the air from all of inlets flows through (figure 7.25.a). From the house section we see that there is zero air speed in the upper area toward the ceiling; consequently the air temperature is high (figure 7.25.b). With respect to this, it is much better to build more openings on the upper wall to let the air flow in and hence reduce the high air inside temperature.



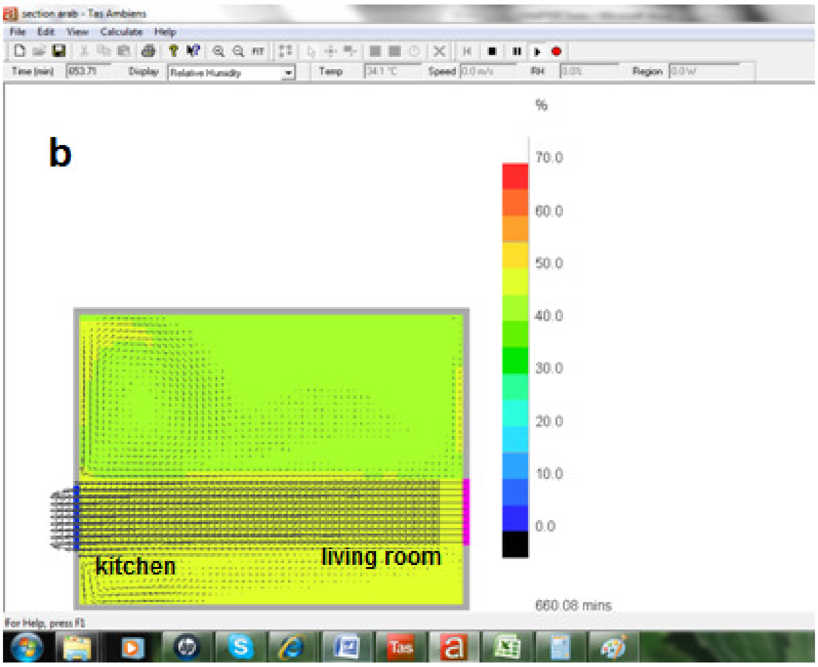




Figure 7.26 The Relative humidity flow on the ground floor (a), and through the section (b) of Saudi Arabia house

The inside Relative Humidity which evenly spreads throughout the layout of the house is similar to the outside value which is about 45% RH. RH value decreases slightly to 40% in the upper area near the ceiling (figure 7.26).

### 7.3.3 IOM Post Tsunami Housing

a. Air temperature

The peak inside air temperature of IOM post tsunami housing is quite high at up to $40^0$C. This high temperature is as the result of the light construction as discussed in the previous chapter. All peak temperatures in the three zones happen on July 26th at around 2-4pm; meanwhile the peak outside temperature occurs on August 3rd (table 7.12).

Table 7.12 inside air temperature performance of IOM house

| Zone | Average Difference between Internal and External (°C) | Peak (°C) | Day of Peak | Hour of Peak |
|---|---|---|---|---|
| External - Banda Aceh 0 latitude | N/A | 36.3 | 215 | 14 |
| Living room | 1.5 | 40.6 | 207 | 16 |
| Bedroom1 | 1.8 | 39.6 | 207 | 15 |
| Bedroom2 | 1.9 | 40.0 | 201 | 14 |

b. PMV and PPD

There are about 57.7% of hours within a year regarded as comfortable ranged in -1<PMV<1 (table 7.13). In these hours the dissatisfaction with regard to thermal performance is only about 0-30%. The interesting thing is despite this percentage which may determine that this house model is nearly comfortable, the worst PPD value (70 %< PPD<100%) also represents a large portion, occurring in 2185 out of 8760 hours (24.9%) within a year. It means that there are also a percentage of hours in a year when people feel dissatisfied with the internal thermal performance (figure 7.27).

Table 7.13 PMV performances of IOM house

| Zone Name | *Outside range* | *-1 < PMV < 1* | *-0.75 < PMV < 0.75* | *-0.5 < PMV < 0.5* |
|---|---|---|---|---|
| living room | 39.45 | 60.55 | 55.27 | 49.49 |
| bedroom1 | 43.94 | 56.06 | 50.76 | 44.83 |
| bedroom2 | 43.52 | 56.48 | 51.29 | 44.89 |
| Average | 42.30 | 57.70 | 52.44 | 46.40 |

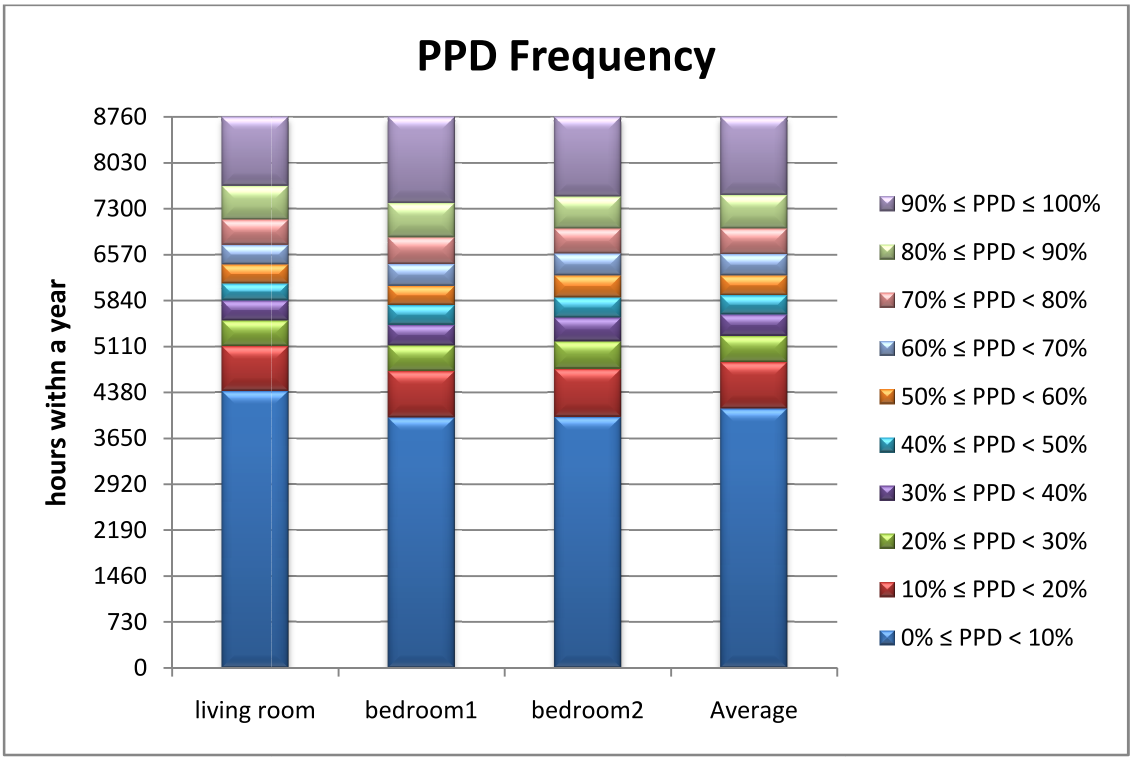



Figure 7.27 PPD performances of IOM house

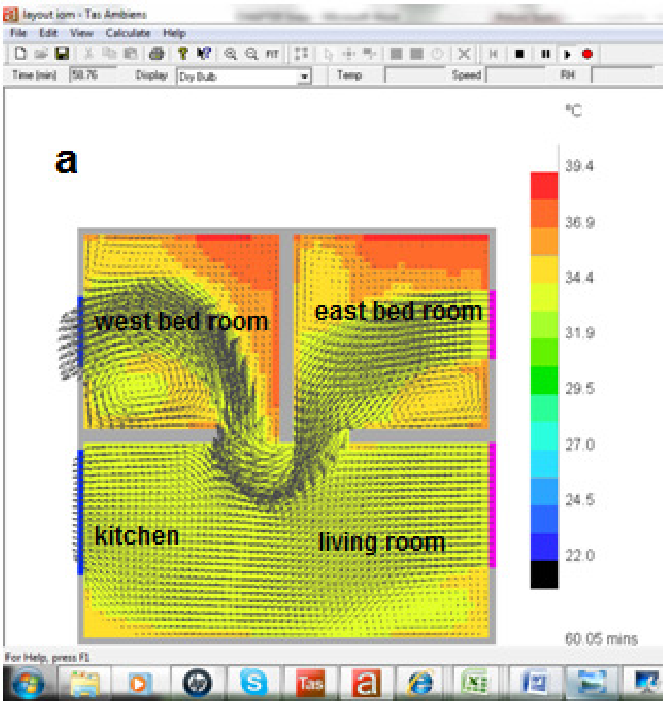
c. TAS Ambient

The TAS ambiens in IOM house is carried out by applying the data of 17th June 2009 at 3pm. These following temperature data are applied (table 7.14):

Table 7.14 Surface temperatures of IOM house

| Temperature of living room surface ($^0$C) | | | | | Temperature of north bed room surface ($^0$C) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wall | Ceiling | Floor | Glass | Door | Wall | Ceiling | Floor | Glass | Door |
| 35.3 | 39.8 | 33.8 | 34.4 | 35.3 | 38.4 | 43.9 | 31.1 | 36.5 | 36.6 |

Following the previous data, the surface temperatures that are not mentioned in the table are estimated to be similar to the close value of nearby rooms.



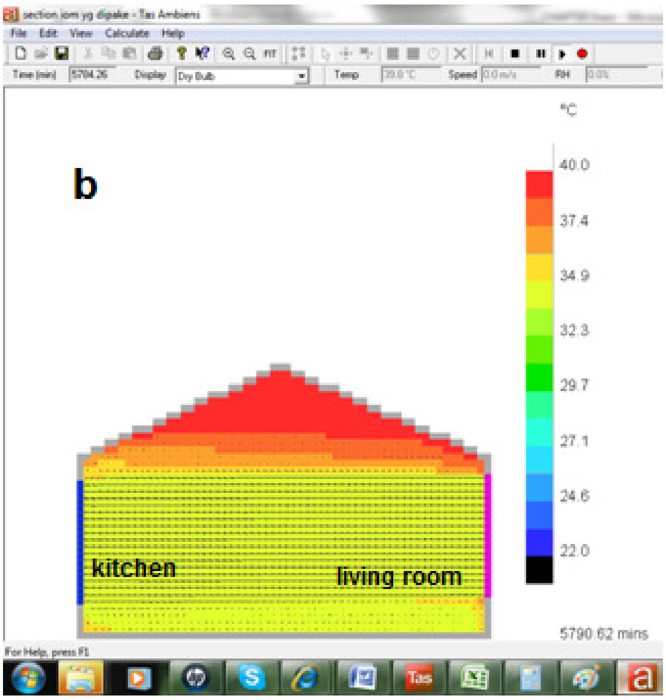




Figure 7.28 The air temperature flow on the ground floor (a), and through the section (b) of IOM house

The opening facing east is estimated to allow the air into the house. It applies these following values: Tao: 33.8$^{0}$C, Rho: 41%, Av: 5.14m/s. The two bedrooms appear to suffer the higher inside temperature compared with the living room which is just equal to the outside temperature. The highest temperature occurs in the upper area close to the roof which is up to 40$^{0}$C (figure 7.28).

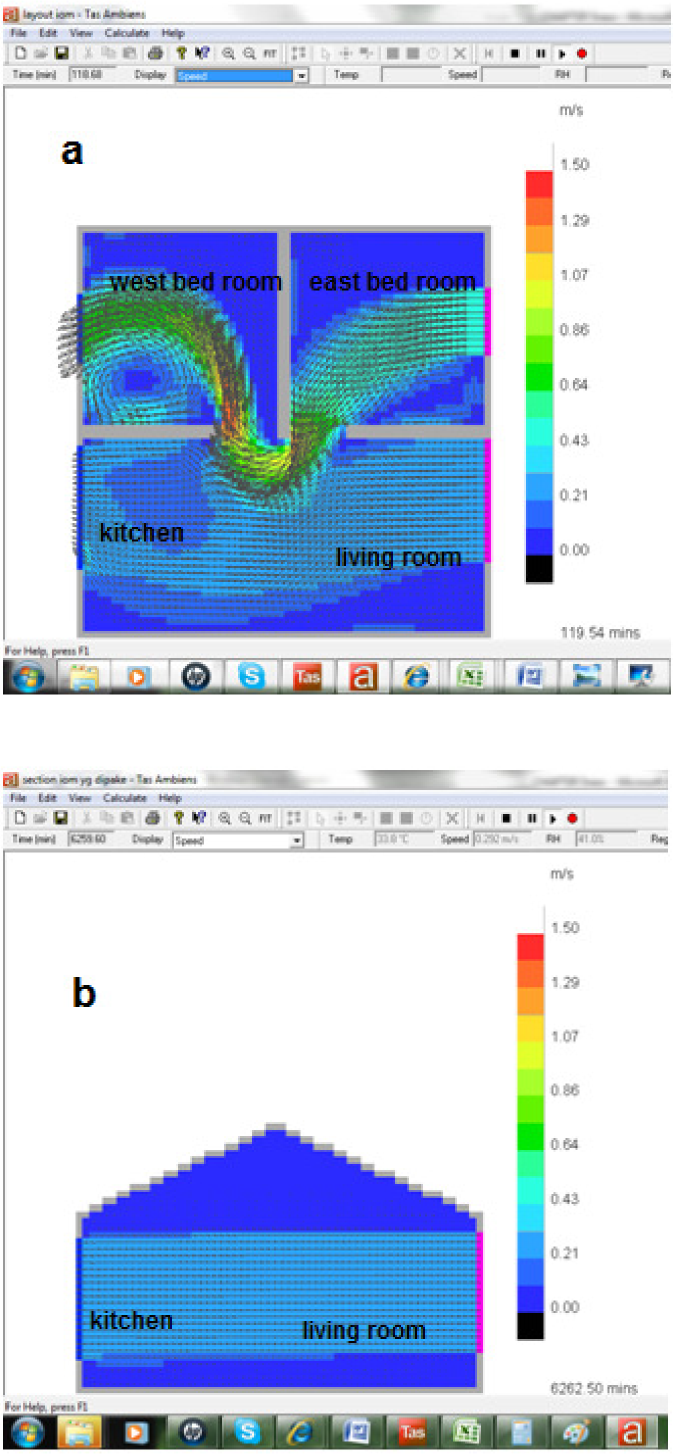



Figure 7.29 The air speed flow on the ground floor (a), and through the section (b) of IOM house

The outside air speed which is around 5.14 m/s is reduced to about 0.4 m/s on entering the house. The air flowing throughout this 36m$^2$ house still has some areas of zero air speed (figure 7.29).

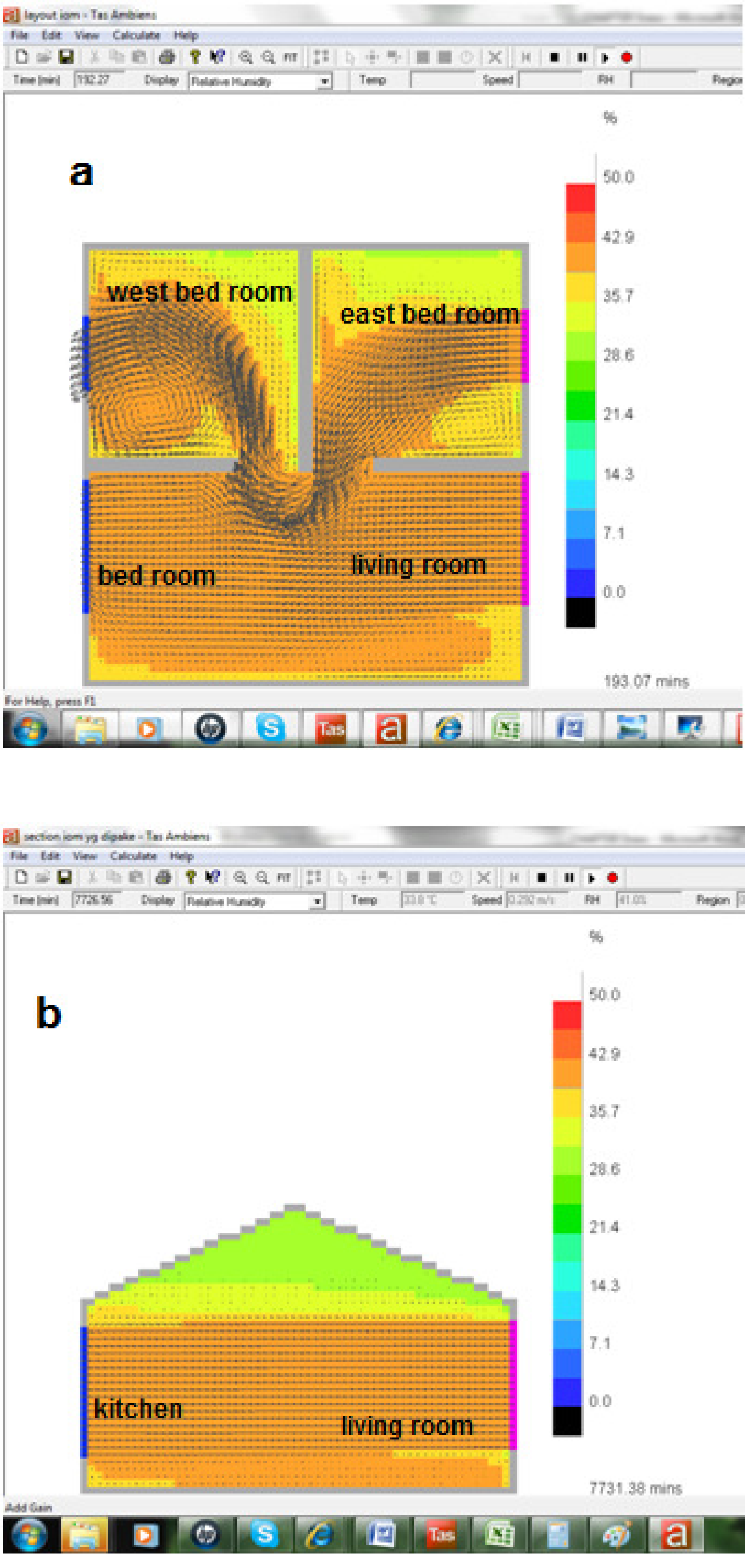



Figure 7.30 The relative humidity flow on the ground floor (a), and through the section (b) of IOM house

Inside relative humidity is similar to the outside RH value which is around 41%. In the ceiling area the value significantly changes down to 28.6% as the temperature increases up to $40^0$C (figure 7.30).

### 7.3.4 Uplink Post Tsunami Housing

a. Air temperature

The Uplink house is a raised floor house built in a combination of brick and wood plank (figure 7.10). The peak inside temperatures in this house model occurs mostly at the same time as the other house models that is on July 26th 2009 at 3 pm, while the outside air temperature reaches its peak value on August 3rd 2009 at 2 pm. The difference between the inside and the outside temperature is quite large, that is 2.06$^0$C. This large number responds to the very high peak inside temperature such as 40.24$^0$C in living room zone.

Table 7.15 Inside air temperature performance of Uplink house

| Zone | Average Difference between Internal and External (°C) | Peak (°C) | Day of Peak | Hour of Peak |
|---|---|---|---|---|
| External - Banda Aceh 0 latitude | N/A | 36.3 | 215 | 14 |
| Livingroom | 2.1 | 40.2 | 207 | 15 |
| Kitchen | 2.1 | 40.0 | 207 | 15 |
| Bedroom | 2.0 | 37.9 | 207 | 15 |

b. PMV and PPD

This house model is predicted to be comfortable (*-1 < PMV < 1)* in about 50.6% on average of hours during a year (table 7.15). During these hours the PPD value is less than 30%. Just as the previous light construction house model, despite the significant PMV and PPD value that may confirm this house to be nearly comfortable, the highest PPD value of 70-100% arises in 32% on average of hours within a year. That percentage shows that there are also quite significant numbers of hours where people will feel uncomfortable in this house model (figure 7.31).

Table 7.16 PMV performances of Uplink house

| Zone Name | *Outside range* | *-1 < PMV < 1* | *-0.75 < PMV < 0.75* | *-0.5 < PMV < 0.5* |
|---|---|---|---|---|
| Living room | 48.09 | 51.91 | 45.97 | 39.28 |
| kitchen | 49.32 | 50.68 | 44.36 | 37.79 |
| bedroom | 50.75 | 49.25 | 42.39 | 35.09 |
| Average | 49.39 | 50.61 | 44.24 | 37.39 |

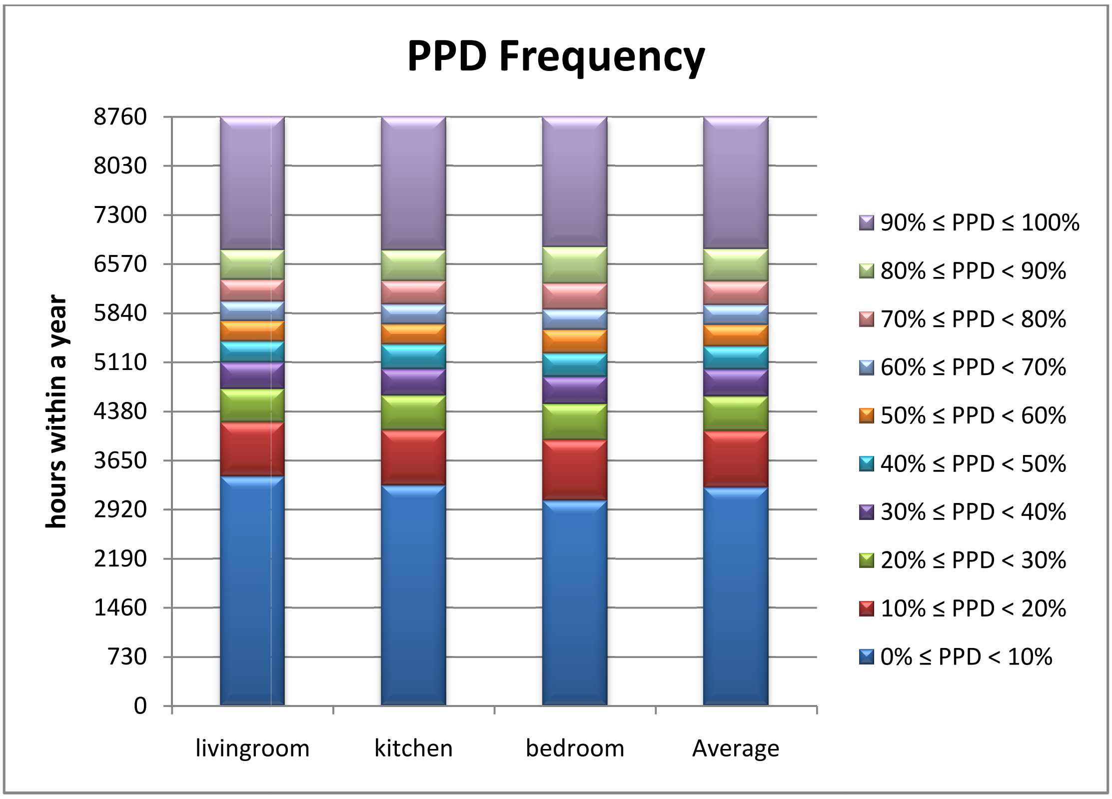



Figure 7.31 PPD performances of Uplink house

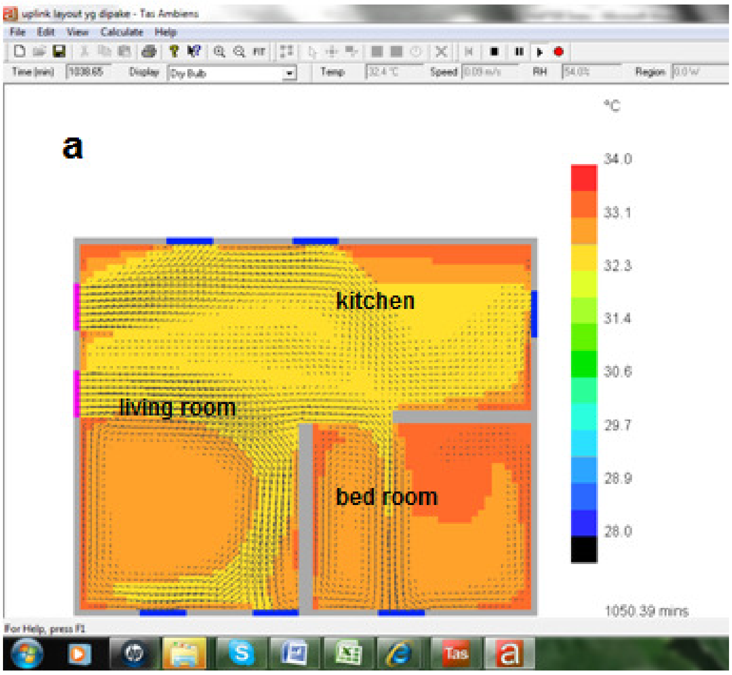
c. TAS Ambient

The dynamic thermal performance is simulated by using the field trip data carried out on May 22nd, 2009 at 11 am. The inlets built in the models apply Tao of 32.4$^0$C, Rho of 54% and air velocity of 1.54m/s. While the building envelopes apply the following data:

Table 7.17 Surface temperatures of Uplink house

| Temperature of living room surface ($^0$C) | | | | | Temperature of north bed room surface ($^0$C) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wall | Ceiling | Floor | Glass | Door | Wall | Ceiling | Floor | Glass | Door |
| 33.5 | 36.3 | 34.5 | 36 | 35.4 | 33.3 | 37.5 | 33.3 | 35.4 | 34.5 |

The temperature of other surfaces that are not mentioned in that table area assumed to be equal to the nearby rooms.



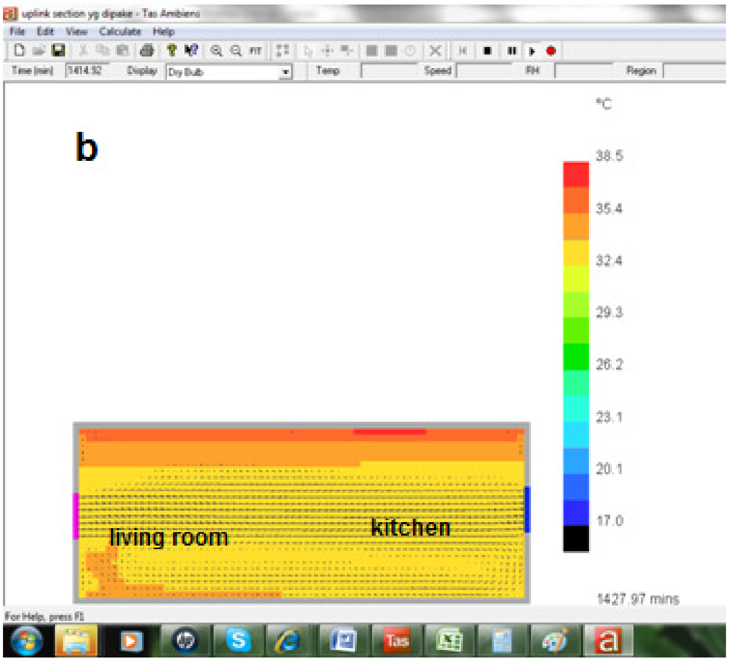




Figure 7.32 The dry bulb temperature flow on the ground floor (a), and through the section (b) of Uplink house

The inlets are marked in pink allowing the outside air in from the west side. This makes the temperature in the kitchen and a small part of the living room zone similar to the outside temperature at about 32$^0$C. Nevertheless the inside air temperature in the bedroom remains higher by 1$^0$C than the outside value (figure 7.32.a). The higher temperature also happens in the ceiling area which gradually moves up to 38.5$^0$C (figure 7.32.b).

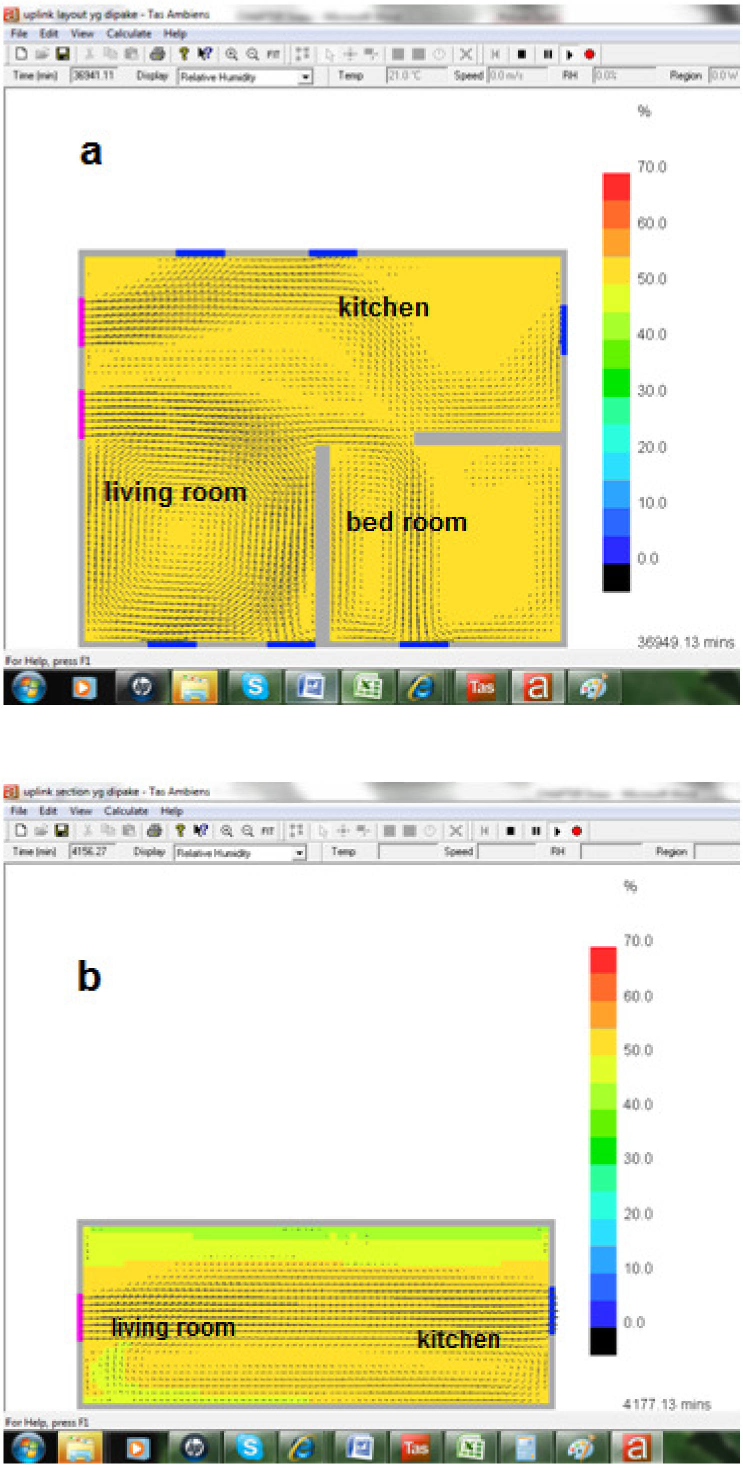


Figure 7.33 The relative humidity flow on the ground floor (a), and through the section (b) of Uplink house

Since the outside and the inside air temperature are almost equal, the relative humidities also remain similar to each other. Following the high upper air temperature near the ceiling, the relative humidity is conversely down to be 40% RH (figure 7.33).

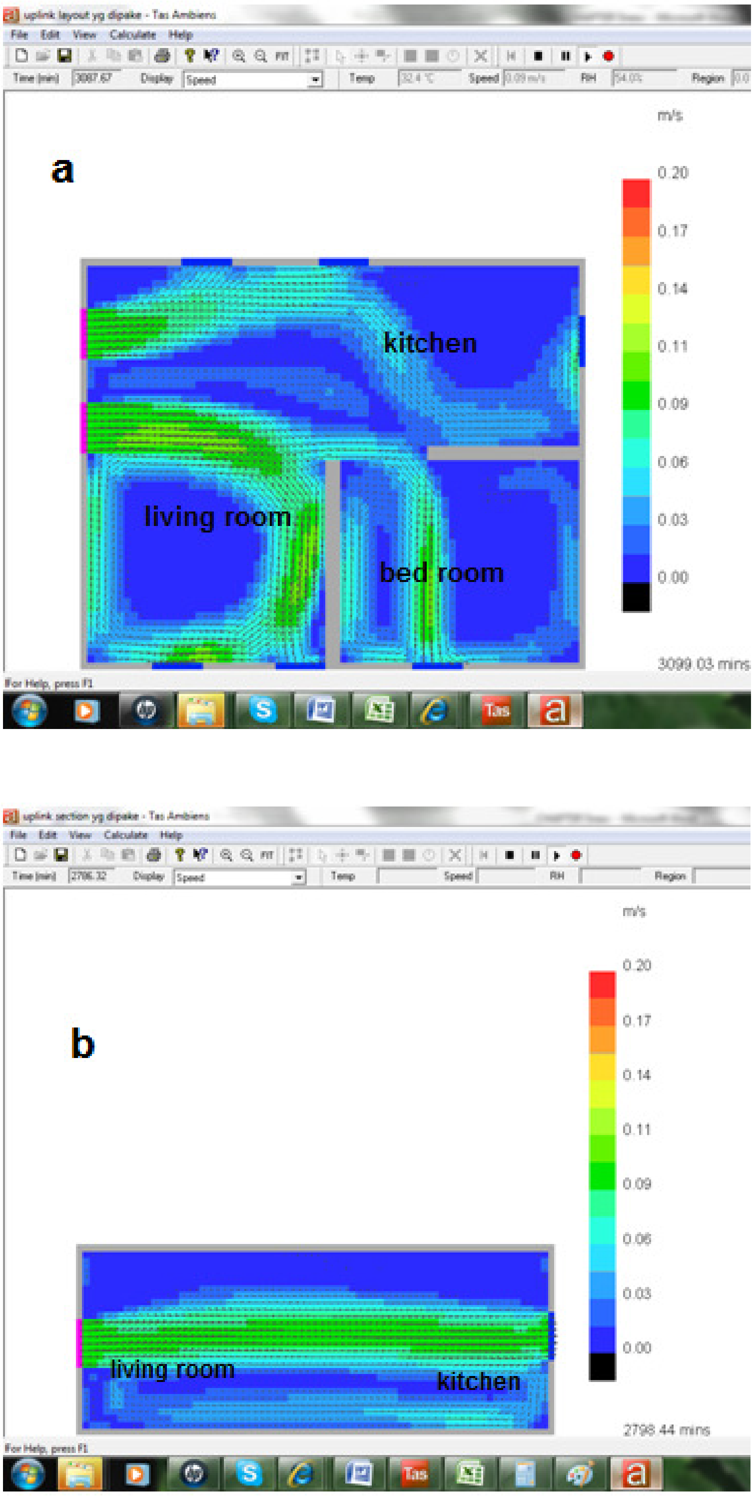



Figure 7.34 The air speed flow on the ground floor (a), and through the section (b) of Uplink house

The inside air is assumed to enter from the pink inlet. Yet, figure 7.34 shows that the flow is not equally spread throughout the layout. In all three zones there remain several points having zero air speed which also happens to the ceiling area which may result in the higher air temperature.

### 7.3.5 YBI Post Tsunami Housing

a. Air temperature

The YBI house is semi permanent house constructed in brick and wood plank the same as the UPLINK house model. It is the single story type built with a floor area of $36m^2$. From the simulation, we see that the peak inside temperature in all of the three zones occurs at the same time as the other most frequent peak temperatures of the previous house models that is on July, $26^{th}$ 2009 at 3 pm. In this house, the average peak temperature is about $37.6^0C$ while the outside temperature is $36.3^0C$ occurring on August 2009 at 2pm (table 7.18).

b. PMV and PPD

Table 7.18 Air temperature performances of YBI house

| Zone | Average Difference between Internal and External (°C) | Peak (°C) | Day of Peak | Hour of Peak |
|---|---|---|---|---|
| External - Banda Aceh 0 Latitude | N/A | 36.3 | 215 | 14 |
| Living Room | 1.0 | 37.7 | 207 | 15 |
| Bedroom1 | 1.5 | 37.5 | 207 | 15 |
| Bedroom2 | 1.6 | 37.6 | 207 | 15 |

Table 7.19 PMV performances of YBI house

| Zone Name | *Outside range* | *-1 < PMV < 1* | *-0.75 < PMV < 0.75* | *-0.5 < PMV < 0.5* |
|---|---|---|---|---|
| Living Room | 43.92 | 56.08 | 50.42 | 44.45 |
| Bedroom1 | 47.82 | 52.18 | 46.64 | 40.16 |
| Bedroom2 | 50.32 | 49.68 | 43.74 | 37.58 |
| Average | 47.35 | 52.65 | 46.94 | 40.73 |

There are 52.6% of hours within a year predicted to be comfortable ranged in $-1<PMV<1$ (table 7.19). This percentage regarded in only 20% of people are dissatisfied with inside air temperature which occurs in about 4313 hours (49.23%) within a year. Just as in the previous light construction house, in spite of this there are about 2762 hours (31.5%) within a year where the PPD reaches its worst value that is around 70-100% (figure 7.35).

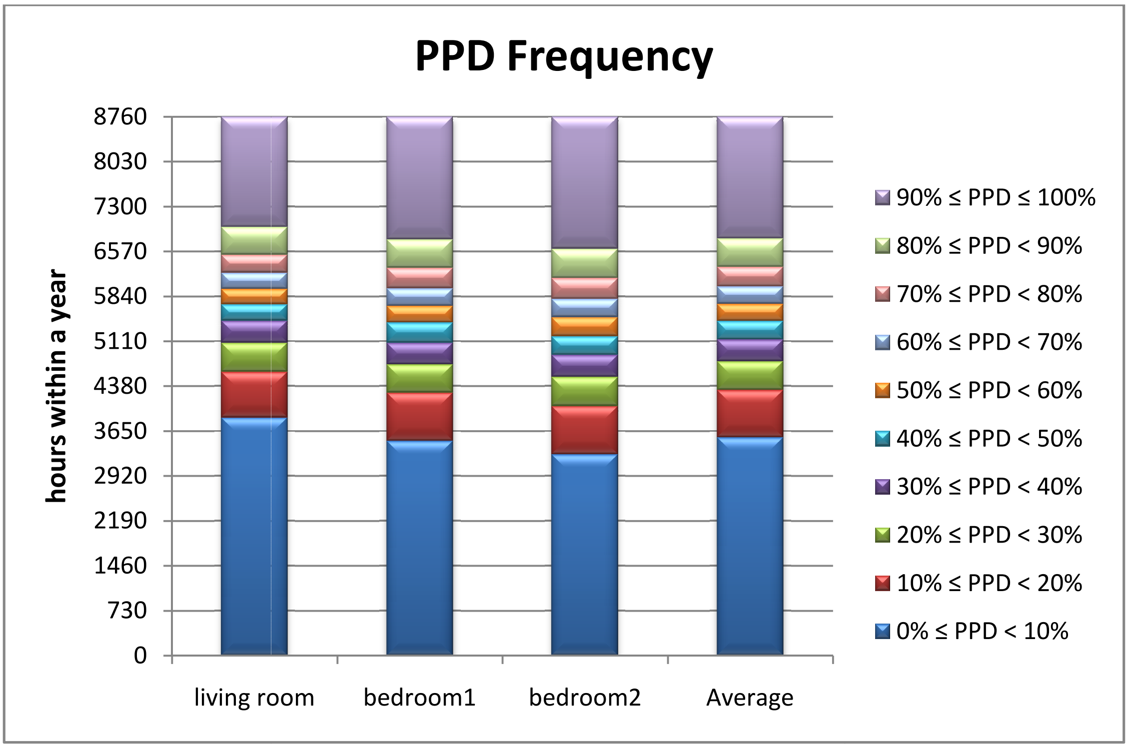



Figure 7.35 PPD performances of YBI house

### 7.3.6 Acehnese Traditional House

a. Air temperature

The peak inside temperatures occur in this house model at the same time as the outside temperature reaches its peak value, that is on August 3rd at 2 pm. The average of inside peak temperature is close to the outside value which is about 36.1$^0$C. Table 7.20 also shows that the inside temperature is close to the outside value.

Table 7.20 Air temperature performances of Acehnese traditional house

| Zone | Average Difference between Internal and External (°C) | Peak (°C) | Day of Peak | Hour of Peak |
|---|---|---|---|---|
| External - Banda Aceh 0 latitude | N/A | 36.30 | 215 | 14 |
| Big livingroom | 0.26 | 36.18 | 215 | 14 |
| Small livingroom | 0.26 | 36.20 | 215 | 14 |
| Bedroom | 1.03 | 35.86 | 215 | 16 |
| Kitchen and diningroom | 0.18 | 36.24 | 215 | 14 |

c. PMV and PPD

This house is regarded as comfortable in 64.8 % of hours within a year ranged in the value of -1 < PMV < 1 (table 7.21). In this percentage, the dissatisfaction of thermal sensation is less than 30% of PPD value. While the worst PPD value ranged in 70-100% occur in only 14.48% of hours within a year (figure 7.36). It may confirm that this house model is quite close to being comfortable.

Table 7.21 PMV performances of Acehnese traditional house

| Zone Name | *Outside range* | *-1 < PMV < 1* | *-0.75 < PMV < 0.75* | *-0.5 < PMV < 0.5* |
|---|---|---|---|---|
| Big Living Room | 32.83 | 67.17 | 61.04 | 54.46 |
| Small Living Room | 33.68 | 66.32 | 60.02 | 53.52 |
| Bedroom | 40.73 | 59.27 | 51.93 | 44.45 |
| Kitchen And Dining Room | 33.41 | 66.59 | 61.11 | 54.59 |
| Average | 35.16 | 64.84 | 58.52 | 51.76 |

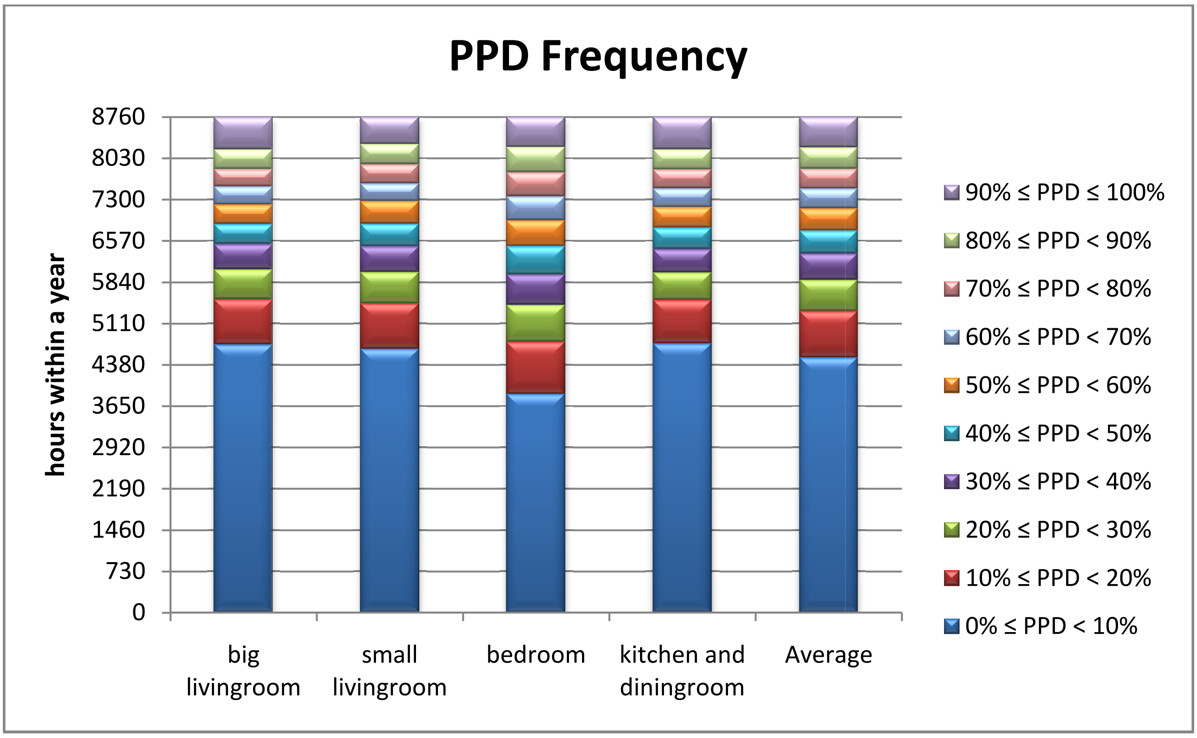



Figure 7.36 PPD performances of Acehnese traditional house

d. TAS Ambiens

The TAS ambient model is carried out using the field trip data of July 6th, 2009. The surface temperatures as shown in the following table 7.22 are applied.

Table 7.22 Surface temperatures of Acehnese traditional house

| Temperature of living room surface ($^0$C) | | | Temperature of north bed room surface ($^0$C) | | |
|---|---|---|---|---|---|
| Wall | Ceiling | Floor | Wall | Ceiling | Floor |
| 33.6 | 33 | 33.2 | 33.3 | 33 | 32.1 |

The other surfaces that were not measured are assumed to apply the temperature of nearby rooms. The short side of the house are always located facing west and east. The inlets are estimated to be on the west side marked in pink and applying these following data: Tao: 30.2$^0$C, Av: 4.8 m/s, and Rho: 57%

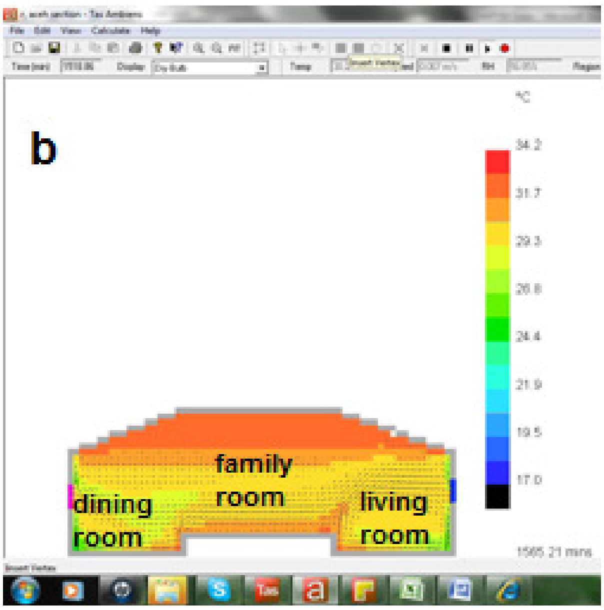




Figure 7.37 The dry bulb temperature flow on the ground floor (a), and through the section (b) of Acehnese traditional house

The outside temperature reduced to be about 29$^0$C applies to the entire layout of the house almost equally. Some higher temperatures which are around 31-33$^0$C occur nearby the inside walls and the ceiling while the outside temperature is 30.2$^0$C (figure 7.37).

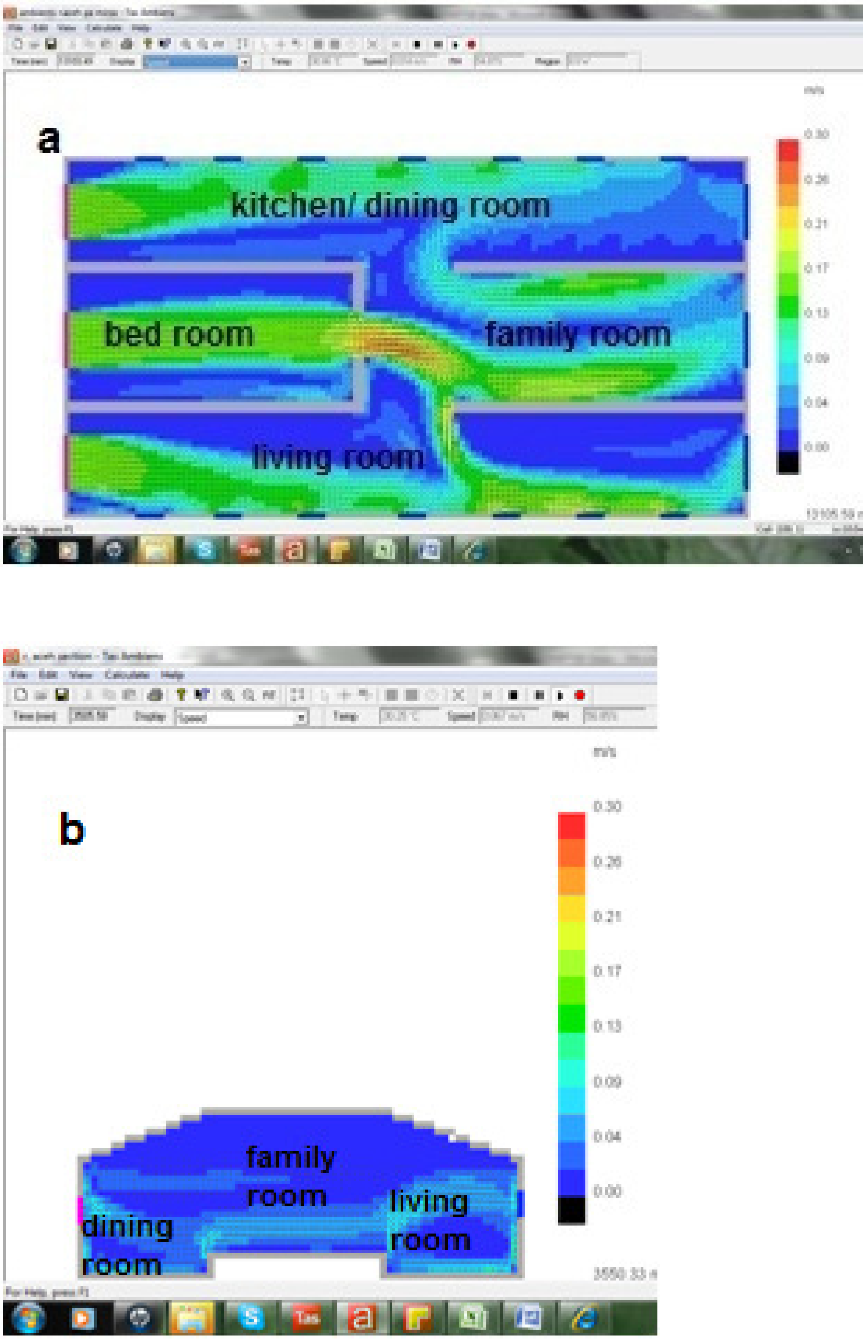



Figure 7.38 The air speed flow on the ground floor (a), and through the section (b) of Acehnese traditional house

The air flowing in to the house layout is reduced to be 0.17m/s coming from the west inlet. Meanwhile the outlet marked in blue allows the air out at 0.09m/s (figure 7.38). The more openings built in the house makes the air flow strongly in and out.

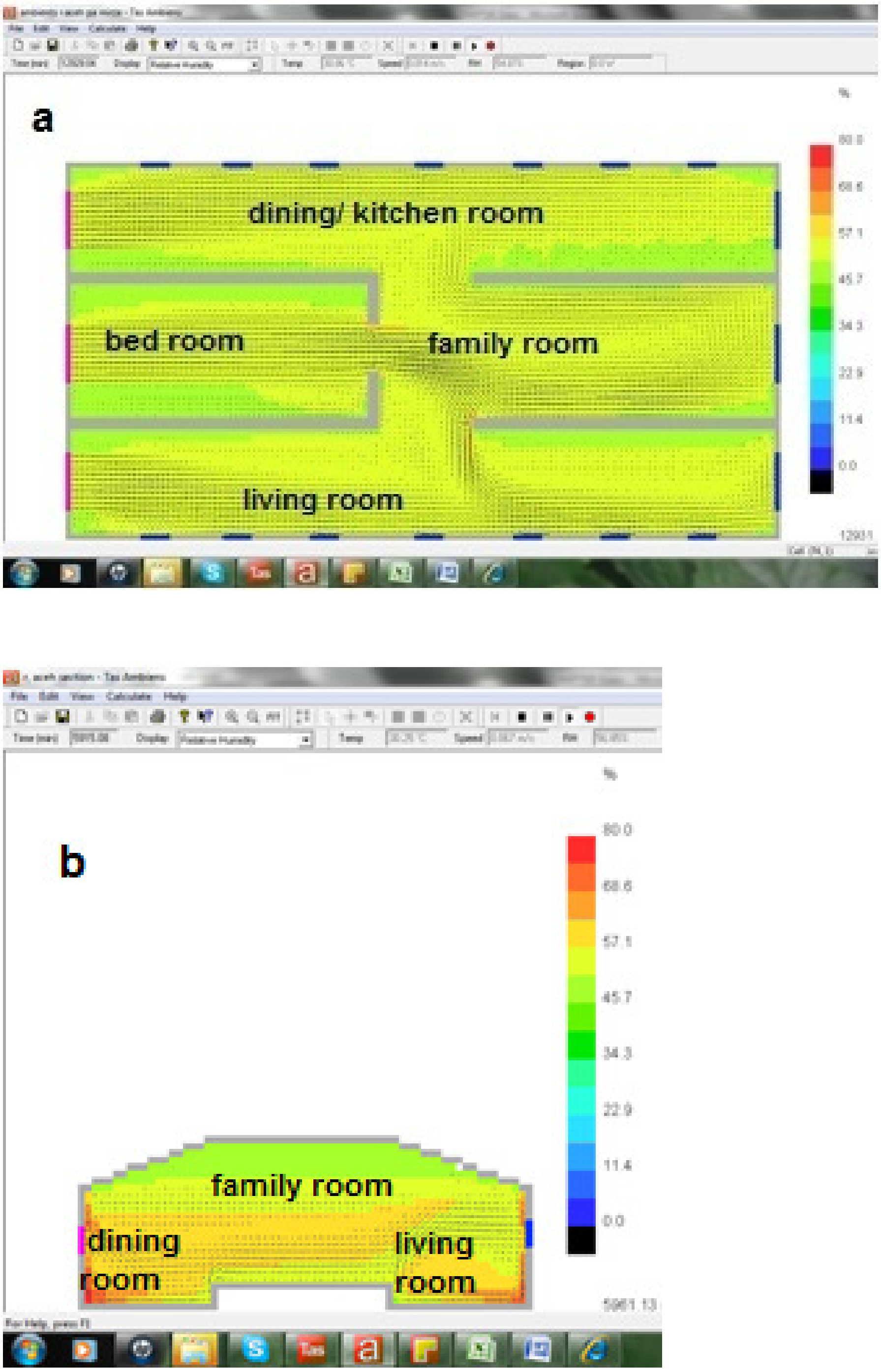



Figure 7.39 The relative humidity flow on the ground floor (a), and through the section (b) of Acehnese traditional house

The inside Relative humidity in the entire layout is around 45-55% which is slightly lower than the outside RH value. However this is very close to comfort humidity range. The highest RH value that is about 80% occurs near the outside wall (figure 7.39).

## 7.4 DISCUSSION

### 7.4.1 General Annual Thermal Performance of Five Post Tsunami Houses Simulated in TAS Software

The thermal environmental performance in this chapter shows the value of air temperature, PMV and PPD value of each house. Figure 7.40 shows that the highest peak inside air temperature occurs in IOM house which is then followed by Uplink house, YBI house, Acehnese traditional house, Saudi Arabia house and World Vision house respectively. Those first four houses are light weight and semi permanent house; therefore as previously discussed these house types suffer the very high temperature which on average can be up to $40^0$C. The inside peak temperatures of those light weight houses occur mostly in July, 26th (day 207) at 3 pm or 4 pm, while the outside peak temperature occurs on August $3^{rd}$ (day 215) at 4pm. Meanwhile, the air temperature in the heavy weight house has its peak value variously throughout the house zone. The upper zone reaches its peak temperature in July the same time as the light weight house does, while the ground zone has it in August the same as the outside peak temperature.

The average temperature difference between the inside and the outside in the light weight house varied from 0.43-1.75K which is lower than the semi permanent house (1.37-2.7K) and the heavy weight house (1.94-2.97K) respectively. This small variation is due to the low specific heat capacity and density of the building envelopes especially roof and wall creating no time lag to store thermal energy.

The interesting thing is that in spite of the very high peak temperature, there are 57.7%-68.8% of hours within a year when the PMV values of these light weight houses are regarded as comfortable which is ranged in $-1 < PMV < 1$ . It is much better compared with the semi permanent (52.65%-56.61%) and the heavyweight houses (18.32% - 44.94%). This better range is due to the inside air temperature that is quite close to the outside temperature. As the result the inside air temperature stays as cool as the outside temperature during evening, night and in the early morning. The only problem that arises in the light weight house is the inside air temperature during the day, which is almost as high as or even higher than the outside air temperature.

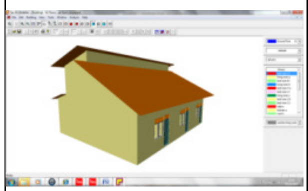
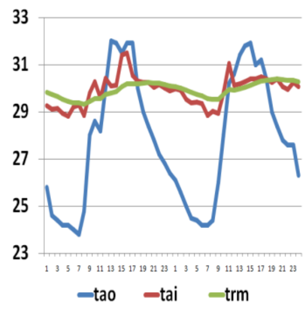
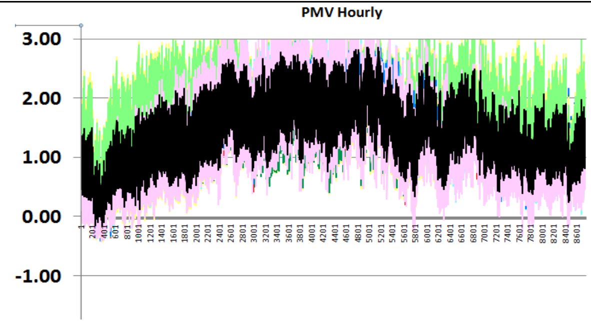
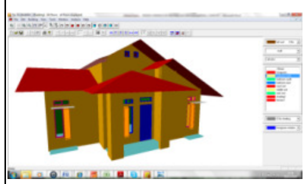
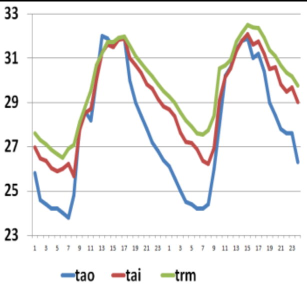
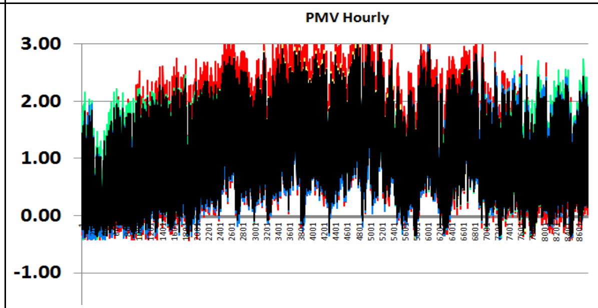
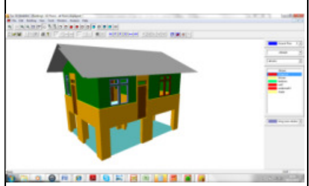
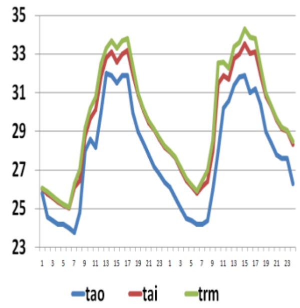
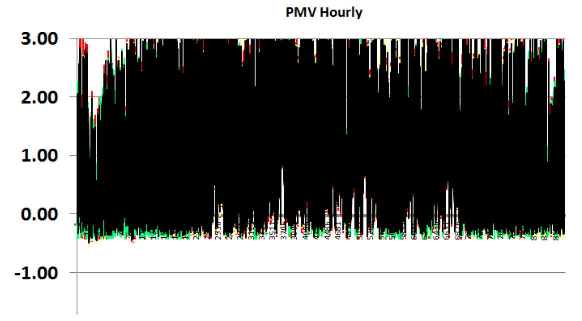
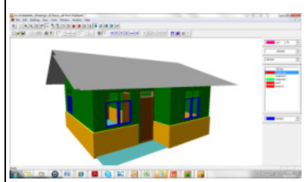
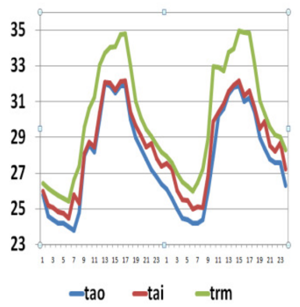
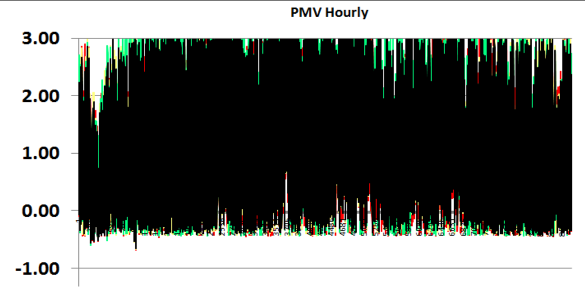
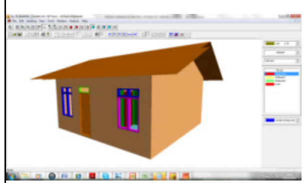
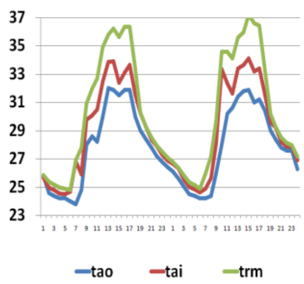
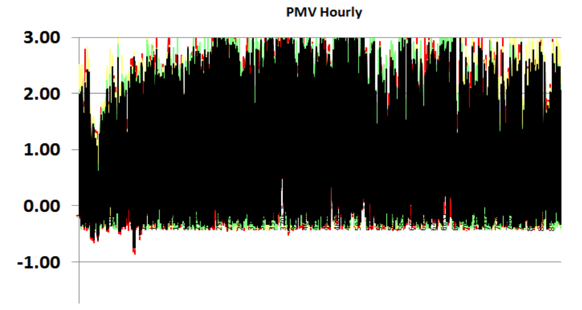
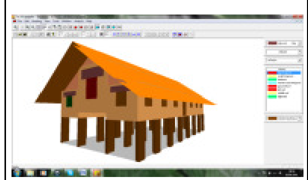
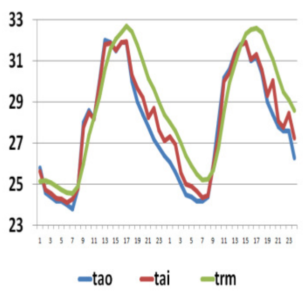
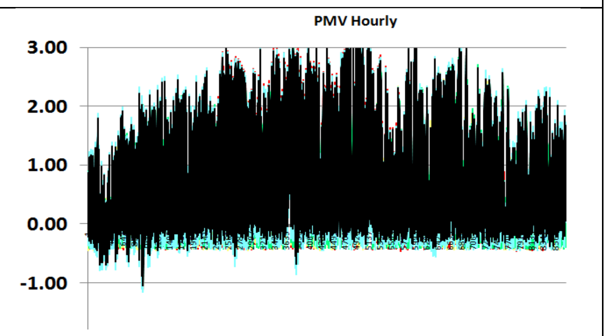
| HOUSE TYPE | SIMULATED HOUSES | INSIDE AIR TEMPERATURE (average) ($^{0}$C) | | Comparison between the inside air temperature and mean radiant temperature Day 125-126, year 2009 | PMV | |
|---|---|---|---|---|---|---|
| | | **Peak tai** | **Avg (tai-tao )** | | **Comfort range** -1 < PMV < 1 | **Hourly PMV Graph within a year** |
| Heavy weight | World Vision House  | 35.2 | 3.0 |   | 18.32 |   |
| | Saudi Arabia house  | 35.6 | 1.9 |   | 44.94 |   |
| Semi Permanent | Uplink house  | 39.4 | 2.1 |   | 56.61 |   |
| | YBI house  | 37.6 | 1.4 |   | 52.65 |   |
| Light weight | IOM house  | 40.1 | 1.8 |   | 57.7 |   |
| | Acehnese traditional house  | 36.1 | 0.4 |   | 68.84 |   |

Figure 7.40 Annual indoor thermal performances of some post tsunami houses predicted by TAS building simulation software

The inside air temperature in the heavy weight house conversely remains slightly cooler than the outside air temperature during the day. Meanwhile during the night it rises up higher than the outside value due to the thermal mass character. This is the reason for having the smaller number of hours within the year whereby the PMV value and hence the PPD value is within the comfortable range. In this house type, Saudi Arabia house is 26.62 % better and more comfortable compared with the World Vision house. The reasons can be from the flexible design of the house with more apertures (figure 7.4) compared with World Vision house (figure 7.1).

Among these houses, the Acehnese traditional house appears to be the best one in term of more hours within the year whereby PMV and hence PPD are comfortable[1]. Due to its light weight character and the use of thatch as the roof material, the inside air temperature is very close to the outside value. Therefore its peak inside temperature is similar to the outside value, that is, 36.1$^0$C, occurring at the same time as the outside peak value, that is August, 3$^{rd}$. Meanwhile the peak temperature in other light weight house is even higher than the outside value, up to 40$^0$C. In addition, figure 7.40 also shows that mean radiant temperature follows the inside air temperature pattern. During the day the mean radiant temperature in light weight and semi permanent houses tends to be higher than the inside and outside air temperature and conversely to be slightly lower in heavy weight house. While during the absence on the sun, the mean radiant temperature in heavy weight house is much higher than the value in the semi permanent and light weight house which is also similar to the pattern of inside air temperature value.

### 7.4.2 TAS Ambiens Simulations

TAS Ambiens simulates the thermal dynamic flow throughout the layout and the section of the house based on the outside thermal data applied to the inlets such as temperature, air velocity and relative humidity. The inlets flow the outside air temperature, relative humidity and air velocity into the house. From figures in sub chapter 7.3 showing the Tas Ambiens works, we see that the areas close to the apertures have similar or slightly lower dry bulb temperature than the outside value, while the area with fewer apertures will remain close to the surrounding surface temperatures such as the bed room in world vision house (figure 7.20). The relative humidity works conversely from the

[1] The comfort range applied in this study : -1 < PMV < 1 and PPD<30%

temperature. As the temperature rises, the relative humidity will decrease and vice versa. Therefore from TAS Ambiens works in the house sections we see that RH value decreases nearby the ceiling area since the temperature rises up closely to be as high as the ceiling temperature. The air in all house designs flows almost evenly, even though there are some small areas which remain at zero air speed, such as the bedroom in the World vision house (figure 7.21). It points to a recommendation to build sufficient openings in all rooms.

## 7.5 Conclusion

The simulation of the post-tsunami houses in this chapter was initially started by validating the models. The validation was carried out by comparing the measured inside air temperature with the simulated one. From these six models, except with the traditional Acehnese house, we see that the indoor temperatures simulated by TAS software are $\underline{+}$1K-2K different from the measured one. While the difference in the Acehnese traditional house is $\underline{+}$2K-4K. The difference may be due to the different solar data and the uncertainties of thermal properties used in the simulation. Apart from the above reasons the large difference of inside temperature in the traditional Acehnese house may also be caused by the trees surrounding the house which can cause the lower temperature, which are not included in the simulation due to the TAS unavailability. Therefore the predicted temperature is higher than the measured one.

The simulation carried out five post-tsunami house models comprising lightweight, semi-permanent and heavyweight houses; and another one traditional Acehnese house. The result shows that the inside air temperature in lightweight houses stays as cool as the outside temperature during evening, night and in the early morning; whereas during the day it is almost as high as or even up to $40^0$C, which is higher than the outside air temperature. The inside air temperature in the heavyweight house conversely stays slightly cooler than the outside air temperature during the day. Meanwhile, during the night it rises up higher than the outside value due to the thermal mass character. Among these houses, the traditional Acehnese house looks to be the best one in terms of providing more thermally comfortable hours within the year due to its lightweight character and the use of thatch as roof material.

# CHAPTER 8 – ANALYSIS OF THE INFLUENCE OF HOUSE DESIGN VARIABLES ON INDOOR THERMAL COMFORT

## 8.1 Introduction

After studying the environmental performance of some post tsunami houses, the further study on house design variables was carried out using TAS building simulation software. The simulations undertaken in this chapter use simple models to which are applied some house design variables to determine the best way to reduce inside air temperature. Building design variables in tropics have been widely studied using various approaches (Prianto et. al., 2003; Tantasavasdi et. al., 2001, 2007; Hanafi, 2010, Lechner, 2001; Maarof et. al., 2009; and Aedhotep Developments, 2011). In this chapter the house design variables are discussed on the following aspects: shape, house orientation, ventilation, shading, building materials, and environmental aspect.

## 8.2 Simulations of House Design Variables Using Several Simple Models

The influence of a number of design variables with respect to meeting indoor thermal comfort requirements in a tropical climate are studied in this section. The building materials simulated in this section are the materials commonly used in Banda Aceh, Indonesia, as the case studied in this research. The weather data applied in these models using TAS simulation is the weather data of Banda Aceh city obtained during the field trip (day 125-126, year 2009) which was measured by the local meteorology office. However, as previously mentioned, since the global and diffuse solar radiation data are not available either from the weather measuring tool or the meteorology office, the data of latitude 0 from Environmental Design, CIBSE Guide A (2006) are utilised.

Aceh climate suffers high peak outside air temperature during the day and remains comfortable during the night and in the early morning. Therefore passive cooling design is the best alternative to cope with such weather. Responding to this, the simulation identifies the result of each measured variable by using the lower peak inside temperature as well as lower night value.

### 8.2.1 Shape

In this section the influence of the building shape on the various inside temperatures is investigated. Therefore no ventilations or openings are applied in some particular models; and the building materials used are in similar construction for the whole building envelope.

#### a. Influence of ceiling height upon inside air temperature

The models are 6x3x2m, 6x3x3m and 6x3x5m shapes constructed in 15 cm brick for the whole building envelope. Two apertures are applied to each model. From the slightly different air temperature data in the three models shown in table 8.1 we see that the higher opaque shape the lower peak inside temperature is. This confirms the suggestions in the literature that buildings in the tropics should be built with high ceilings to reduce the inside temperature (Karyono, 2010). High ceilings help to maximize air movement and hence reduce the inside air temperature (Pearson, 2011).

Table 8.1 Influence of ceiling height upon inside air temperature

| | tao | 6x3x5-aperture | 6x3x3-aperture | 6x3x2-aperture |
|---|---|---|---|---|
| Avg | 27.8 | 29.1 | 29.0 | 29.0 |
| Max | 32.0 | 32.1 | 32.3 | 32.4 |
| Min | 23.8 | 25.1 | 25.0 | 24.9 |

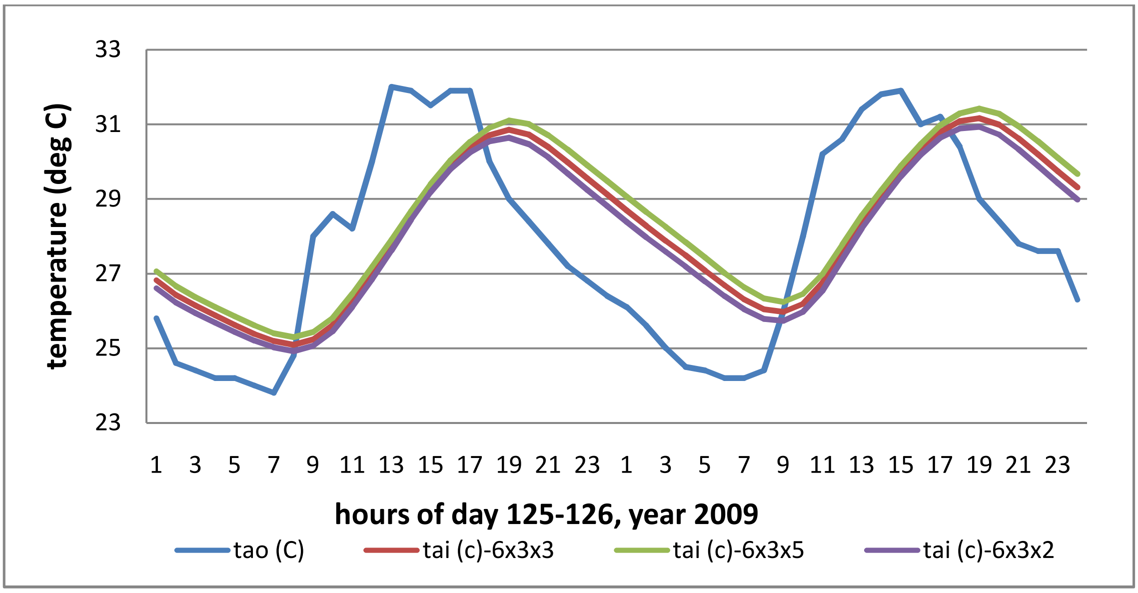



Figure 8.1 Influence of wall height upon inside air temperature

Nevertheless TAS software recognizes that in the case of an opaque shape (building without any apertures) then the opposite may occur. Figure 8.1 shows that the higher the shape the higher inside air temperature is. It is due to the higher external wall which allows a greater surface to be heated by the sun.

In order to decrease the temperature as is mostly required in a hot humid tropic climate, the higher opaque shape should be designed with sufficient openings supplying air to cool the inside building, yet this should also be applied along with other design criteria to reach the expected lower temperature which is shown on the next chapters.

**b. Influence of floor area upon inside air temperature**

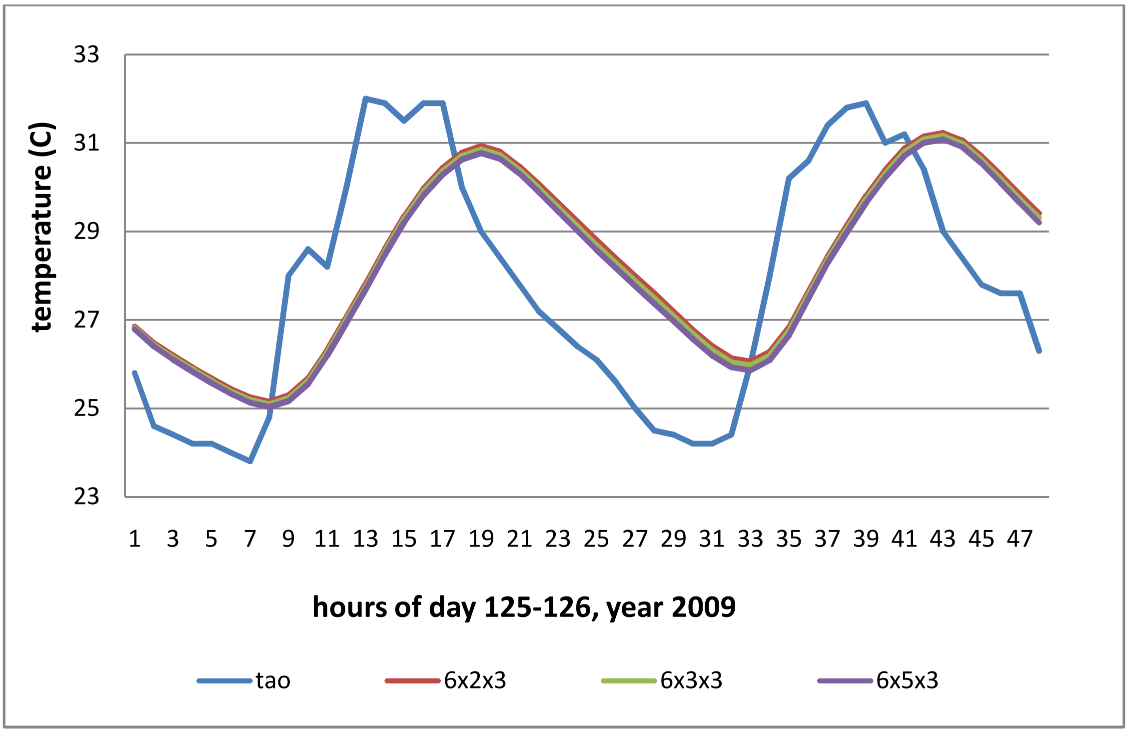



Figure 8.2 Influence of floor area upon inside air temperature

The above figure 8.2 shows the simulation result of opaque shapes with different floor area. The wall heights are fixed at 3cm. In general there are no so significant differences among those models. However, the very slight differences show that the larger the shape area the lower the inside temperature is.

### c. Influence of shape towards inside air temperature

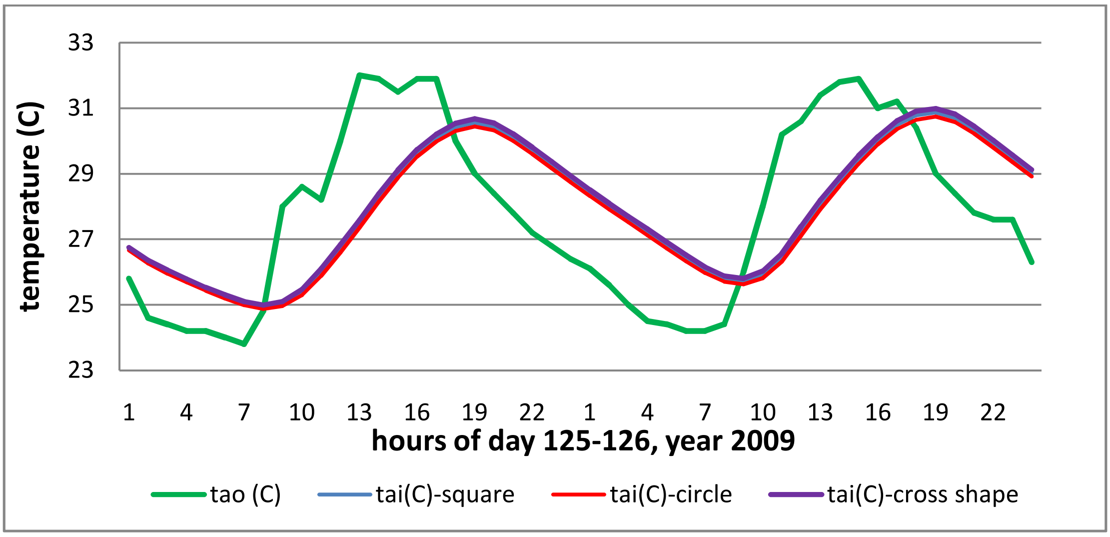



Figure 8.3 Influence of shape towards inside air temperature

Three different shapes such as square, cross and circle with the roughly similar volume of 185 $cm^3$ and areas of 65 $cm^2$ are simulated (figure 8.3). The perimeter area including external wall and ceiling are as follows: 203.40$cm^2$ for cross shape; 164.62$cm^2$ for square; and 155.72$cm^2$ for circle. Despite the very slight difference, the graph shows that the more surfaces exposed to outside, the higher the inside temperature, and vice versa.

### d. Influence of roof shape upon inside air temperature

The roof as the most surface heated by the sun is investigated by simulating four different roof types. The most common roof types simulated are flat, gable, gambrel and hip roof.

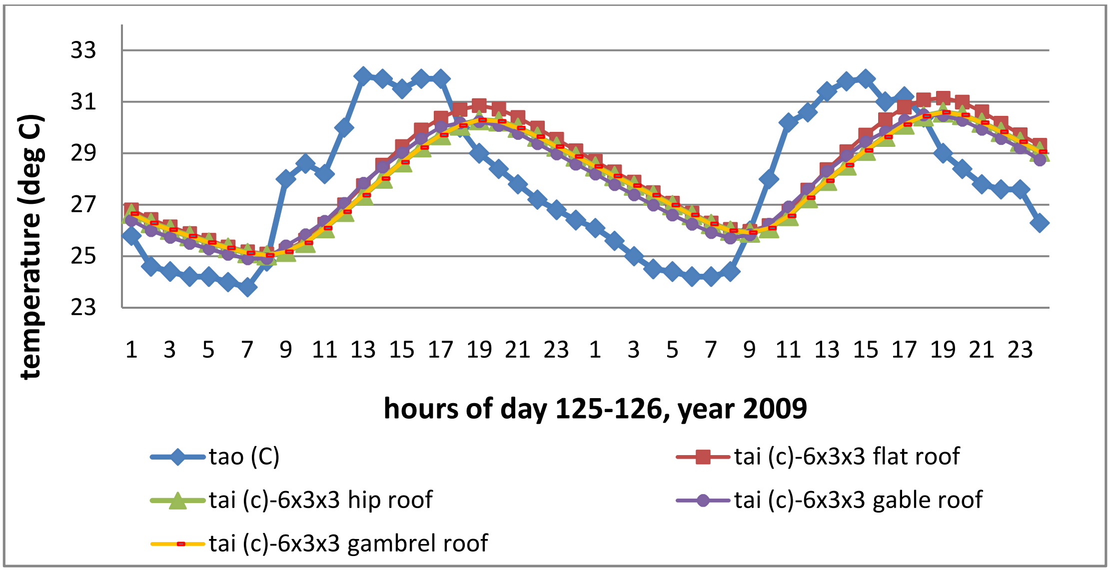



Figure 8.4 Influence of roof shape upon inside air temperature

Figure 8.4 shows that the inside temperature in the flat roof is the highest value compared with the other three roof types. Pitch roofs such as gable, gambrel and hip roof are shown to produce lower inside air temperatures. There is almost no significant difference in inside air temperature among the pitched roofs; nevertheless the gable roof appears to give the lowest value. It may be for this reason that the gable roof is the typical roof type used in Indonesia and even in the Acehnese traditional house.

### e. Influence of height of floor above the ground upon inside air temperature

The following simulation  shown in figure 8.5 was conducted to determine whether the height of the floor above the ground influenced the inside temperature. Based on TAS software calculation, the raised floor house gives a higher inside air temperature than the grounded-floor house can provide, by $2^0$C. It is thought that this is due to the heat transferred into the raised house that is more than in the grounded one. The raised floor house has more surfaces exposed to the air by including the under floor that is indirectly heated by the ground radiation.

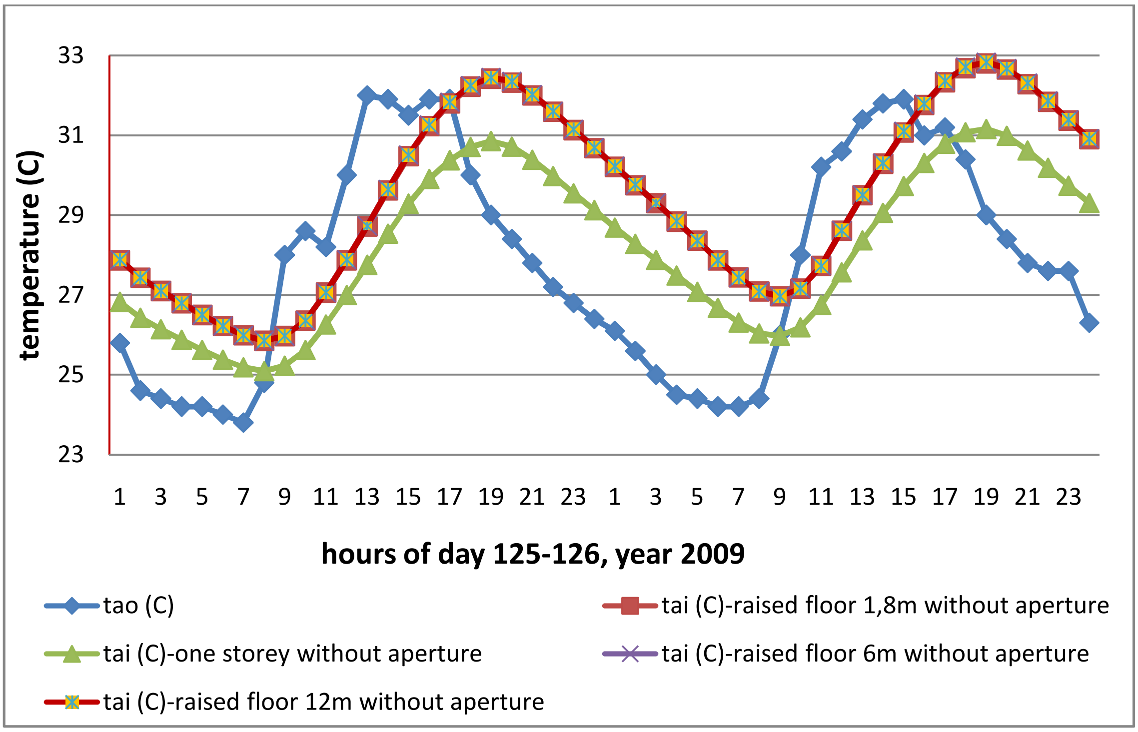



Figure 8.5 Influence of height of floor above the ground upon inside air temperature

Nevertheless, figure 8.5 shows that there is no temperature difference by lifting the floor either up to 1.8m, 6m or 12m above the ground. The inside air temperature remains the same. It does not consequently show that the higher the floor above the ground the higher inside air temperature is. Yet, the floor height of 1.8m above the ground can be said as the optimal height of zone to suffer higher inside air temperature. The grounded floor house has lower temperature due to the attachment of the floor on the ground causing the heat loss. Therefore if the choice is made to build a raised floor house on such height for other reasons, sufficient openings must be applied, and some other design criteria used to achieve indoor thermal comfort.

### 8.2.2 House orientation

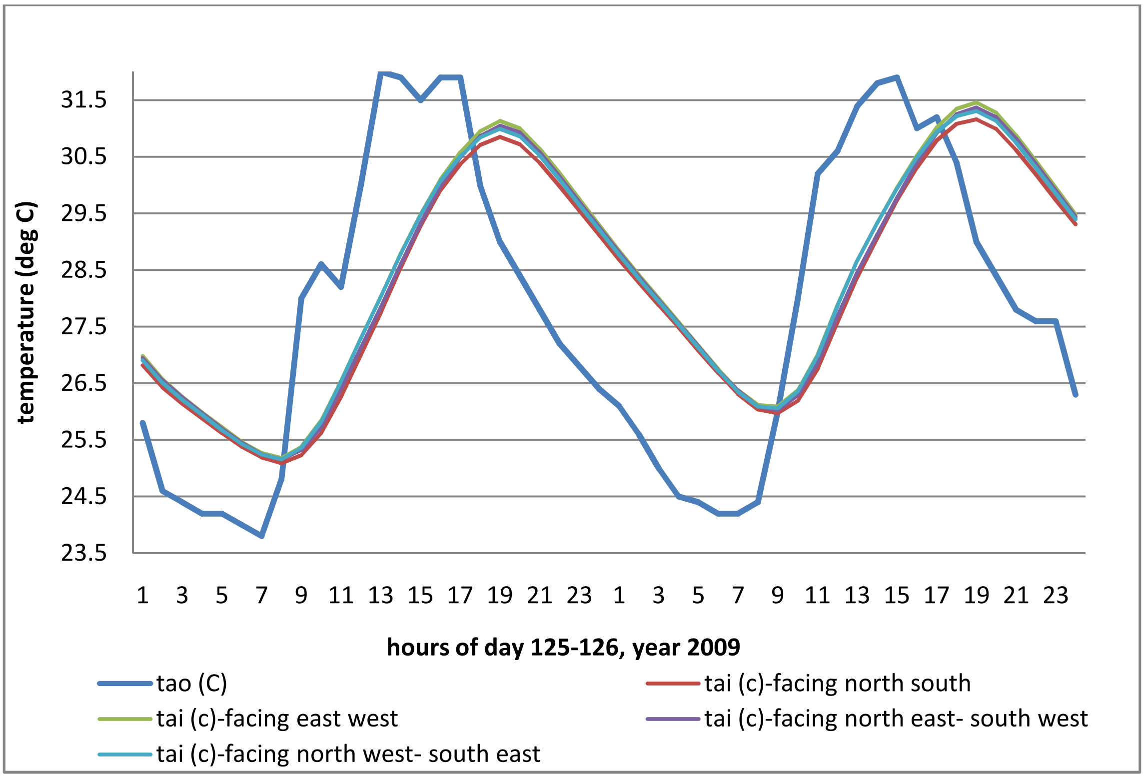



Figure 8.6 Influence of orientation towards the sun upon the inside air temperature

Almost all the literature recommends that houses or any buildings should be built with the large orientation or long side facing north-south. The TAS building simulations show the same result. The chart shows that buildings in the tropics with the long side facing north and south can decrease the peak of day inside temperature by about $0.3^0$C from the buildings facing west and east. The graph (figure 8.6) also shows that even though orienting the building to north east-south west and to north west-south cannot create a temperature as low as toward north- south, but it is slightly better by being lower than the value in east and west orientation. This small difference is valuable to improve the expected indoor temperature.

### 8.2.3 Ventilation and Shading

**a. Influence of opening value of aperture upon inside air temperature**

Four models with pitched roof corresponding with the ventilation assessment are simulated shown in figure 8.7. Three of the models apply two apertures with opening values of 0, 0.2, and 1, which respectively mean 0%, 20% and 100% of the aperture areas are opened for 24 hours, while the remaining model is designed without any apertures. TAS shows that the model with 1 opening value has the highest peak temperature close to the outside temperature trend lines. Conversely, the model without aperture has the lowest peak value, yet the highest during the morning. It summarizes that the larger the opening area, the closer the inside air temperature is to the outside value.

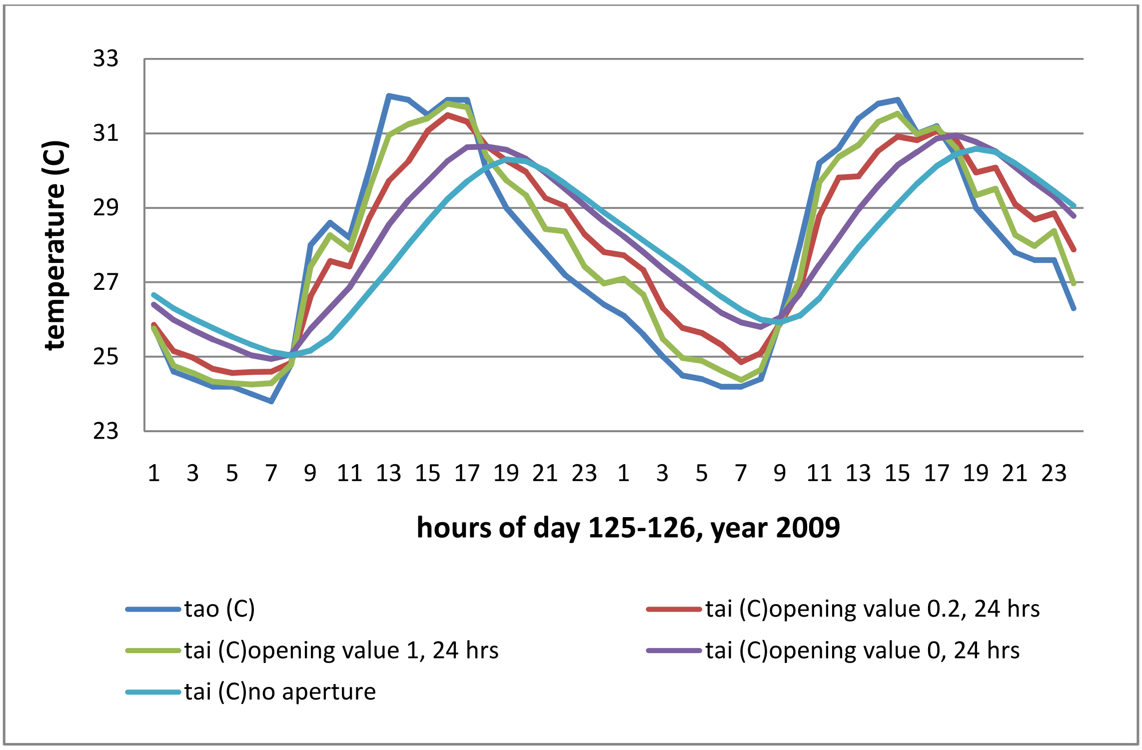



Figure 8.7 Influence of opening value of aperture upon inside air temperature

Those models present higher inside air temperatures compared with the models designed without any apertures. According to the writer, this result does not imply that we should choose to design buildings without any apertures to obtain lower inside air temperature, since openings are really related to view provisions, fresh air supply, and hence the occupants' psychology and health. Therefore, other design criteria should be approached to improve the inside air temperature provided by buildings with apertures to meet the comfort temperature.

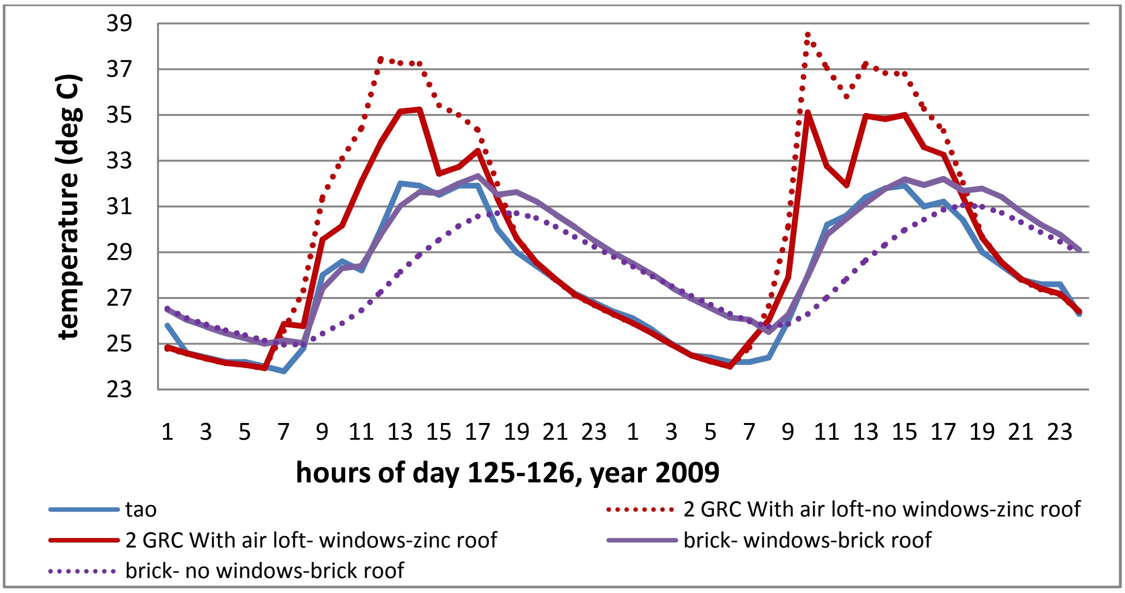



Figure 8.8 Influence of surface temperature and openings toward inside air temperature

Figure 8.8 and 8.9 show that the building materials which easily become hot or instantly transfer the outside heat in to the building such as light weight material (GRC wall and zinc sheet) need sufficient openings to reduce the inside air temperature. In contrast, the heavy weight material with its ability to trap the heat and resist instant transfer of the heat into the building are advised to have few or limited openings to reduce the inside air temperature. In other words, more openings in heavy weight house may result in higher inside air temperature (figure 8.10).

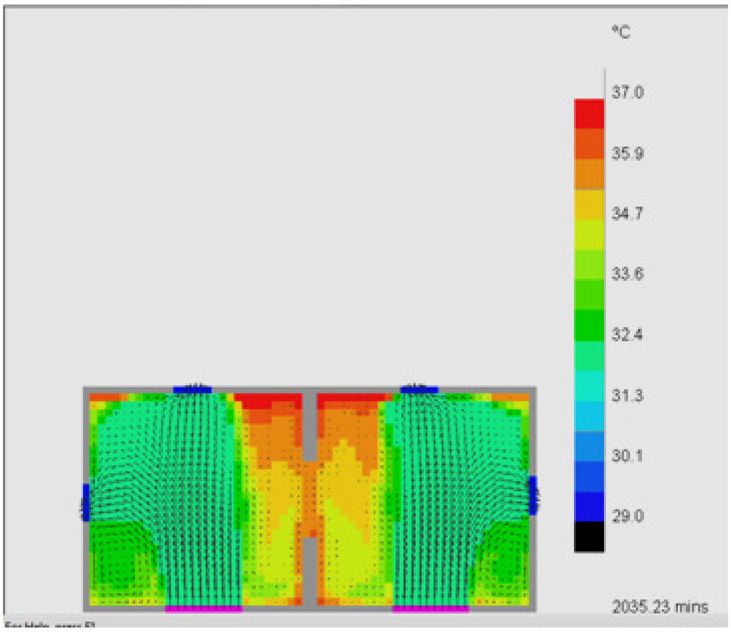



Figure 8.9 Openings in the building with high surface temperature will reduce the inside air temperature.

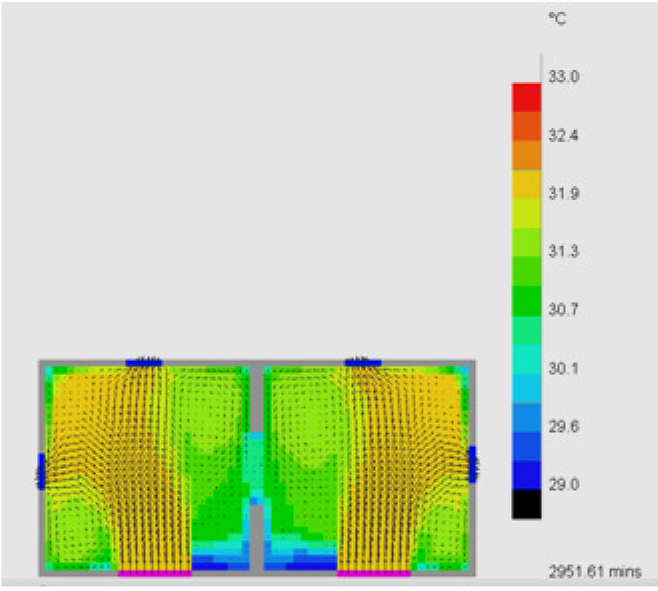



Figure 8.10 Openings in the building with low surface temperature will increase the inside air temperature.

**b. Influence of air movement upon inside air temperature**

Figure 8.11 shows the effect of outside air movement on decreasing the inside air temperature. Corresponding with this, the 6x3x3m shape built in bricks is modelled applying two apertures. The aperture materials are glass with 0.2 of opening value which is open from 7am-6pm during the day. The outside wind speed is simulated variously such as 0m/s, 5m/s, 10m/s and 20 m/s. The result shows that the higher the wind speed the lower the inside temperature. If there is no wind speed at all the inside air temperature is extremely high which is even higher by about $2^0$C than the outside air temperature.

Among these models, 5m/s wind speed works more effectively to decrease the air temperature. This is because there is no significant difference between the influence of 10m/s and 20m/s wind speed in reducing the inside air temperatures, which are close to the value created by 5m/s wind speed. Another result shows that it is difficult to reduce the peak inside temperature during the day by the influence of wind speed alone. It is shown that the three wind speeds give a similar value of the peak inside air temperature to the outside air temperature.

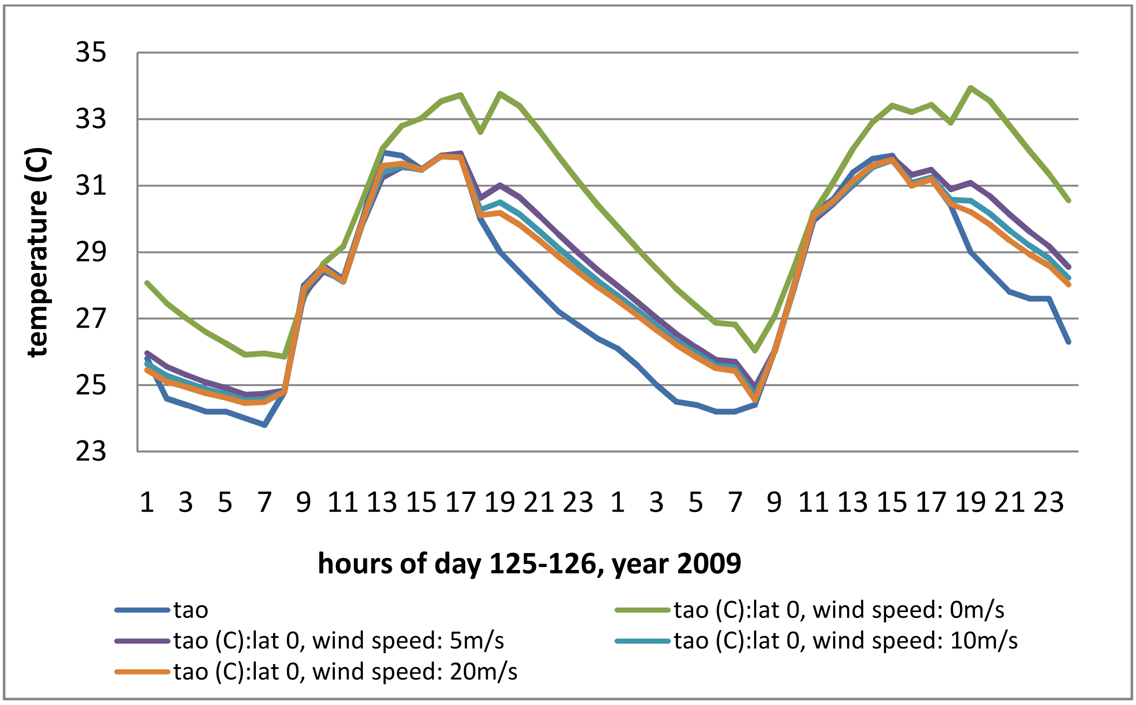



Figure 8.11 The influence of outside air speed upon inside air temperature

### c. Influence of shading upon inside air temperature

Shading using either sloping or flat planes, or fins, are other design variables recommended in much of the literature that can be considered to decrease the inside air temperature in buildings with apertures.

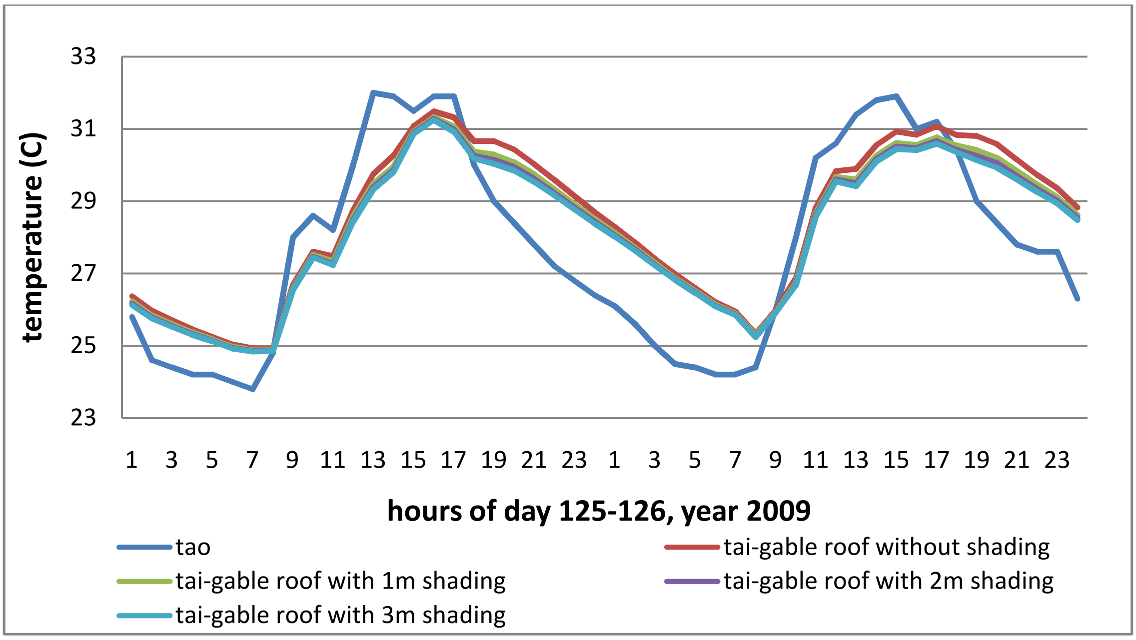



Figure 8.12 Influence of width of shading or overhang along the roof and house perimeter upon inside air temperature

Figure 8.12 shows the result of using the roof shade in reducing the air temperature. The wider the shade the lower inside air temperature. Nevertheless there appears to be no significant difference in inside air temperature achieved by enlarging the shade to 2 or 3 meters wide compared with a one meter wide shade. It is therefore recommended to enlarge the roof shade to 1m wide in order to achieve an indoor temperature almost as low as with a 2 or 3 meters wide of roof shade. This can be understood as the result of the area located on the latitude of $0^0$ where the sun can go directly from the zenith to the nadir and from the nadir to the zenith; and therefore experience the quickest rates of sunrise and sunset in the world (Wikipedia, 2011).

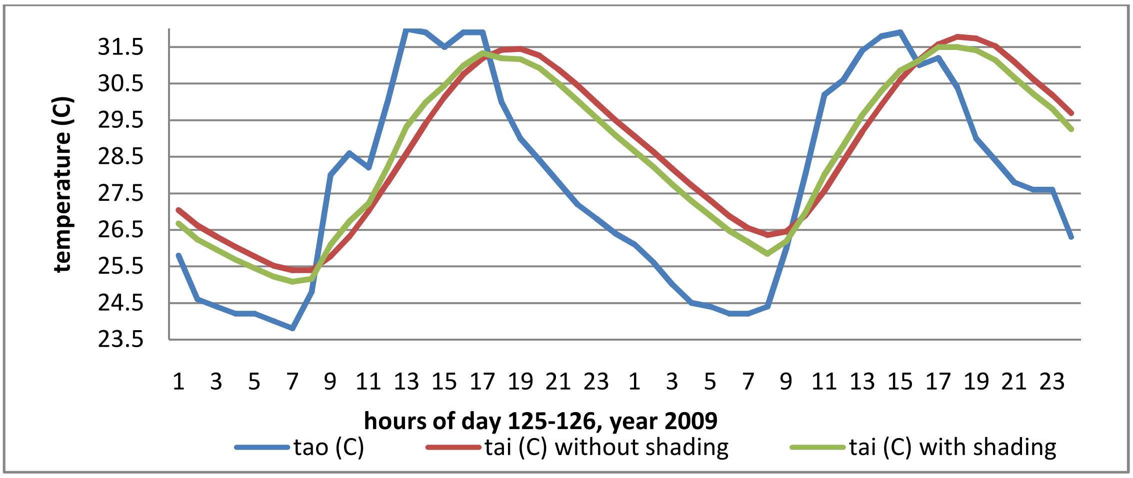



Figure 8.13 Influence of shading above the window upon inside air temperature

Figure 8.13 above shows that the model using the single two meters sloping shading can decrease the inside air temperature provided by the building without any shading as low as that in the model with horizontal fins (figure 8.14). It appears to give only a small improvement in decreasing the internal temperature; nevertheless it will be valuable by keeping it combined with other design variables.

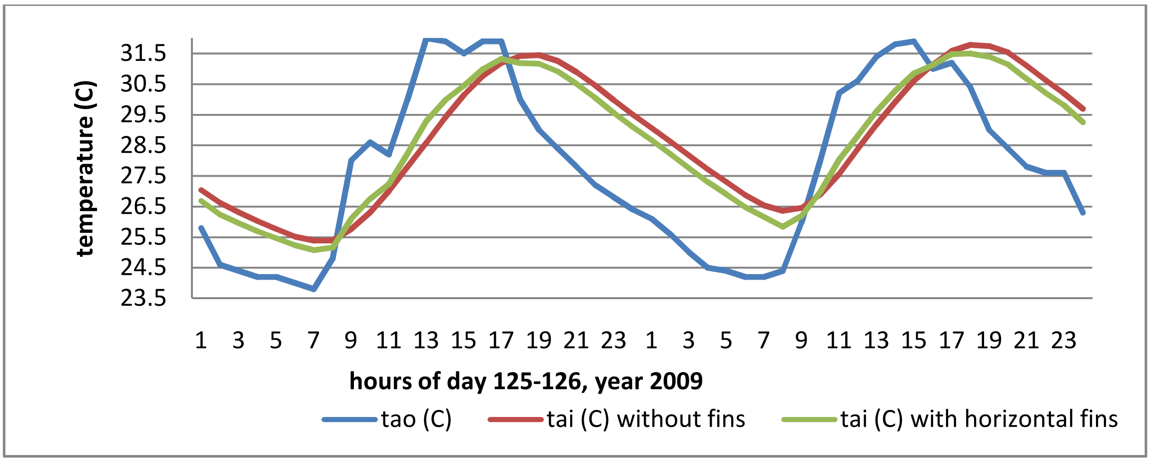



Figure 8.14 Influence of the use of fins in the window upon inside air temperature

### 8.2.4 Building Materials

**a. Influence of roof materials upon inside air temperature**

This following figure 8.15 presents four models using five different roof materials specified as follows: clay tile, aluminium and zinc roof, three common roof materials used in current Indonesian house; thatch, the traditional roof material; and brick as the representative of high thermal mass roof materials. The wall material for the models is brick. All materials are adopted from the TAS building material. Figure 8.15 shows that clay tile roof with the two different conductivities give the highest inside air temperature. Aluminium, zinc and brick follow thereafter respectively. The Thatched roof gives the lowest value of inside air temperature, due to its quite low conductivity value compared with other roof materials.

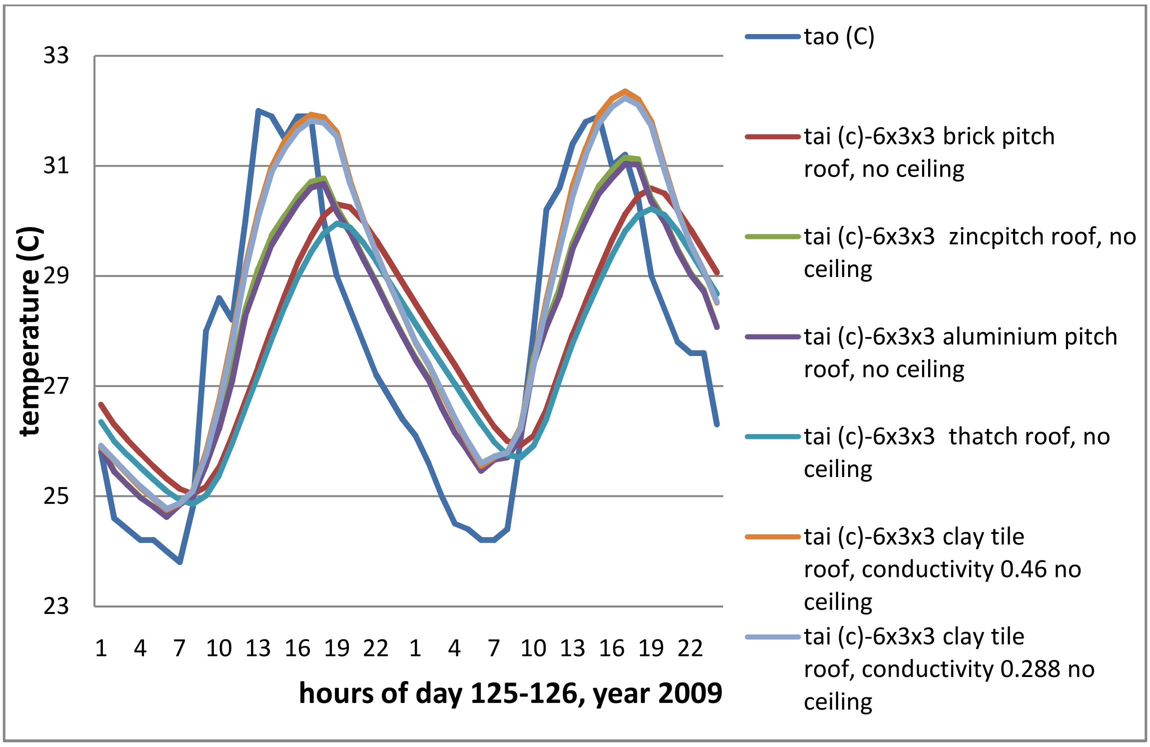



Figure 8.15 Influence of roof materials upon inside air temperature

**b. Influence of wall materials upon inside air temperature**

The common wall materials used in post tsunami house constructions are brick, concrete (batako), plywood, timber, fibreboard, GRC, and gypsum. These materials with 10mm width are simulated and shown in the following figure 8.16:

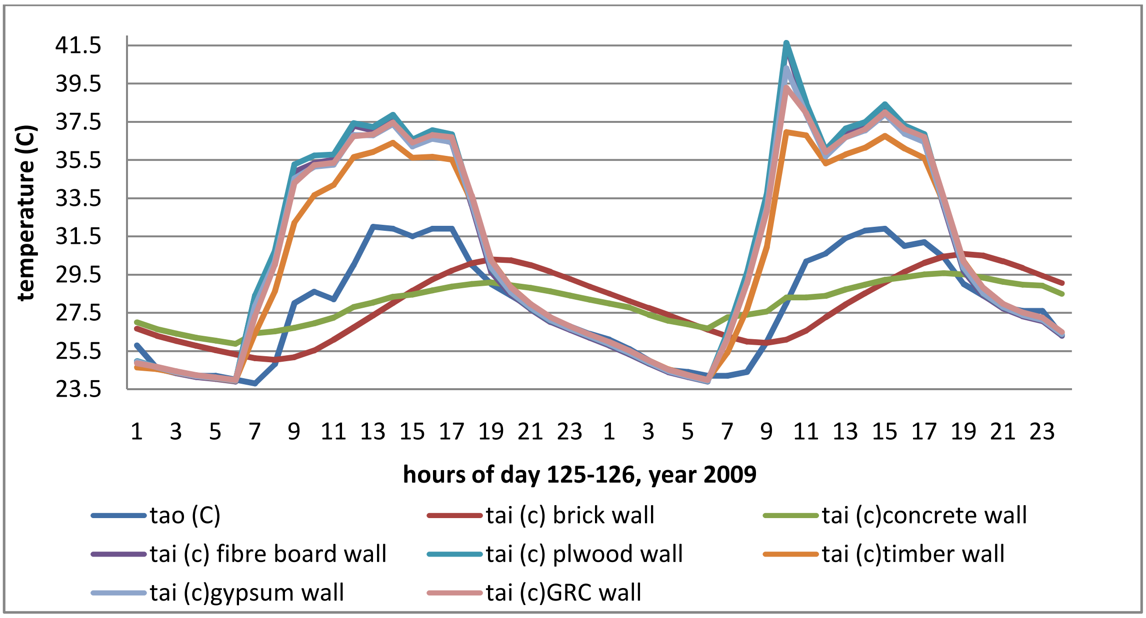



Figure 8.16 Influence of wall materials upon inside air temperature

Figure 8.16 shows that the light weight materials (fibre board, gypsum, GRC, plywood and timber) give very high inside air temperatures which are up to about $5^0$C higher than the outside air temperature during the peak day and up to $7^0$C higher than with the heavy weight materials (brick and concrete). The heavy weight materials are shown to decrease the inside air temperature which is lower by 2-$3^0$C than the outside air temperature. However the air temperature during early morning is higher than the value in light weight construction due to its thermal mass character that is able to store the heat during the peak day and release the heat after about few hours later.

**c. Influence of floor materials upon inside air temperature**

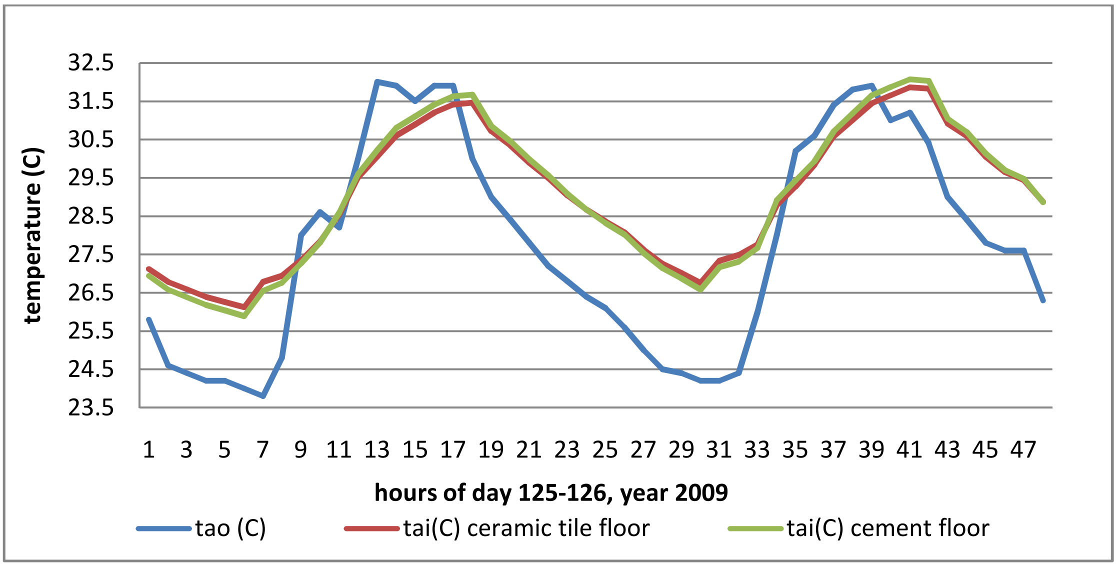


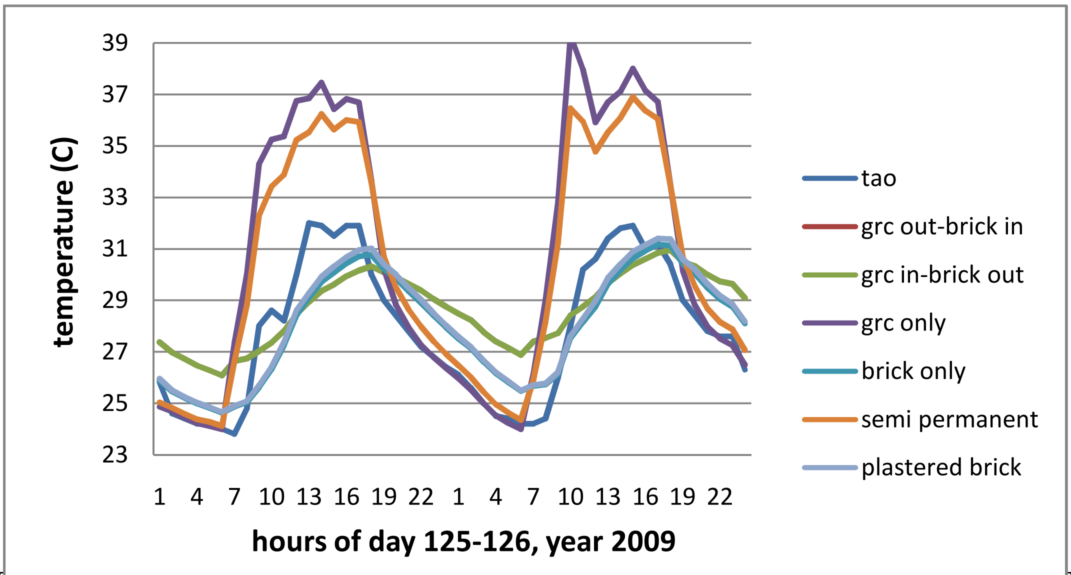

Figure 8.17 Influence of floor materials upon inside air temperature

Floor materials commonly used in Indonesian house constructions are cement plaster and ceramic tile. Therefore these two materials are simulated and give the results as shown in the above picture. Figure 8.17 shows that the ceramic tile floor gives the lower inside air temperature. Nevertheless the temperature difference is not significant compared with the cement plastered floor.

### d. Influence of wall construction upon inside air temperature

The following figure 8.18 shows the result of simulation carrying out a model applying several wall constructions, namely:

1. Using single 3 mm GRC sheet
2. Using single 15cm brick work
3. Using 15cm brick work for the half bottom part and 3mm GRC sheet as another half top part (semi permanent or half permanent wall construction)
4. Using the combination of 3 mm GRC sheet as the outer wall layer; 15cm brick work as the inside wall layer; and 10cm air as the inner fill of the cavity between the two materials.
5. The opposite way to number four: using the combination of 15cm brick work as the outer wall layer; 3 mm GRC sheet as the inside wall layer; and 10cm air as the inner fill of the cavity between the two materials.




| | tao | grc out-brick in | grc in-brick out | grc only | brick only | semi permanent | plastered brick |
|---|---|---|---|---|---|---|---|
| avg | 27.8 | 28.7 | 28.7 | 30.6 | 28.0 | 30.3 | 28.1 |
| max | 32.0 | 31.0 | 31.0 | 39.3 | 31.2 | 36.9 | 31.4 |
| min | 23.8 | 26.1 | 26.1 | 24.0 | 24.6 | 24.1 | 24.7 |

Figure 8.18 Influence of wall constructions upon inside air temperature

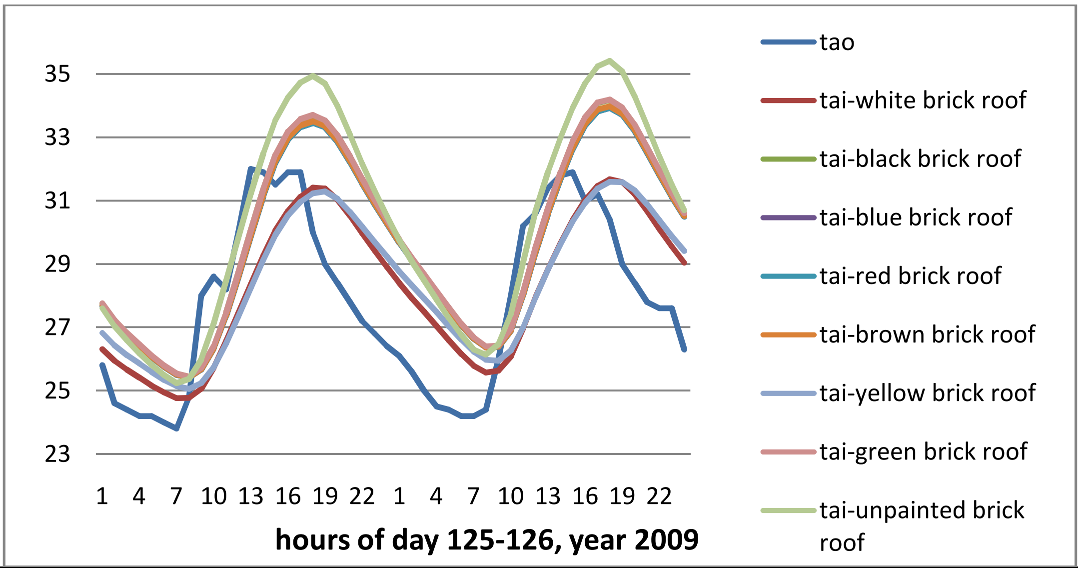
Number 1, 2 and 3 are the common wall constructions in post tsunami housing, while number 4 and 5 are the alternative ways to build using the same typical materials.

Figure 8.18 shows that using GRC sheet only as the wall material produce the highest inside temperature which is up to $39^0$C while the peak outside temperature is only $32^0$C. Undertaking the semi permanent or half permanent which is commonly applied as the wall construction raises the inside air temperature up to $36.9^0$C which is just almost as high as the value in GRC sheet only. Brick wall construction can decrease the peak outside air temperature by $1^0$C; yet raises the minimum air temperature also by $1^0$C due to the time lag. Meanwhile the two alternative ways show the slightly lower peak inside air temperature compared with the value in brick wall construction. Nevertheless it creates the minimum temperature up to $27^0$C which is higher by $3^0$C than the outside temperature. Having such an inside air temperature during night and early morning will not be voted as pleasant by the occupants. The last, plastered brick construction which is currently the most typical wall construction in Indonesia gives an even slightly higher value by $0.4^0$C than just using the single bare brick.

**e. Influence of material colours upon inside air temperature**

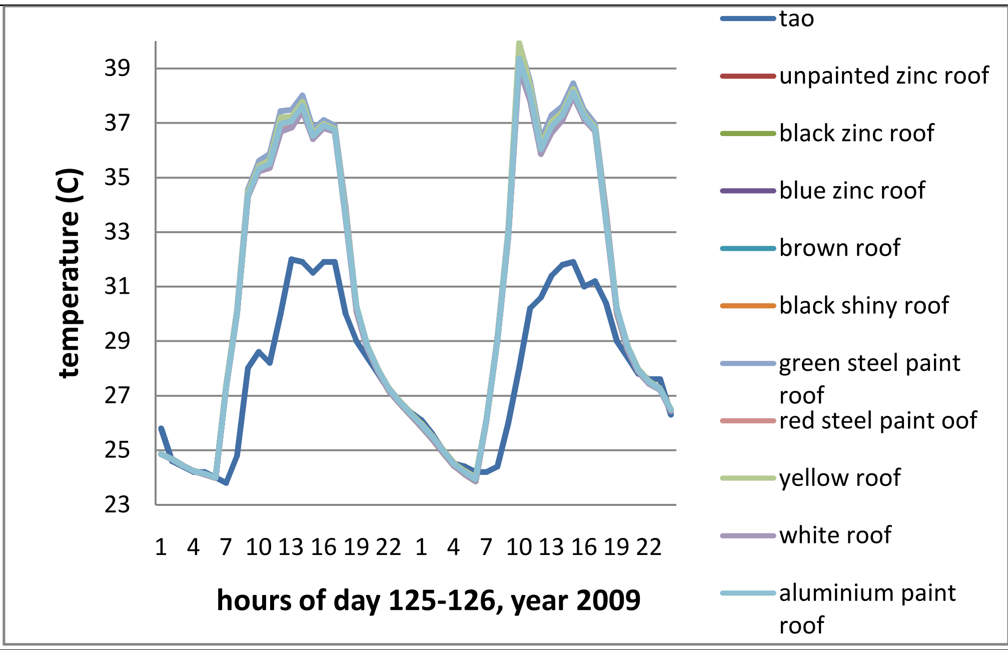
Choosing the colour or paint of the external building envelops can be considered to reduce the inside air temperature to the certain comfort level. In this section external roof and wall will be simulated by painting in various colours.

Two simulations on the painted roof were carried out. The first simulation was the painted brick roof while another one was the painted zinc roof. Figure 8.19 shows that light colour such as yellow and white can reduce the peak inside temperature of the unpainted brick roof by $2.7^0$C. Meanwhile the dark roof such as black, blue, brown, and green create the high inside air temperature which is by $2^0$C higher than the outside value. In contrast figure 8.20 shows that TAS simulates the painted zinc roof to have no significant difference in air temperature reduction. The average, maximum and minimum value of inside air temperature in those various colours are similar to the value from the unpainted zinc roof. The white zinc roof is shown to provide the lowest peak inside temperature, however it is only a very small difference compared with the other colours.




| | tao | tai-white brick roof | tai-black brick roof | tai-blue brick roof | tai-red brick roof | tai-brown brick roof | tai-yellow brick roof | tai-green brick roof | tai-unpainted brick roof |
|---|---|---|---|---|---|---|---|---|---|
| avg | 27.8 | 28.3 | 29.8 | 29.7 | 29.7 | 29.7 | 28.4 | 29.8 | 30.3 |
| max | 32.0 | 31.7 | 34.2 | 33.9 | 33.9 | 34.0 | 31.6 | 34.2 | 35.4 |
| min | 23.8 | 24.8 | 25.4 | 25.4 | 25.4 | 25.4 | 25.1 | 25.4 | 25.2 |

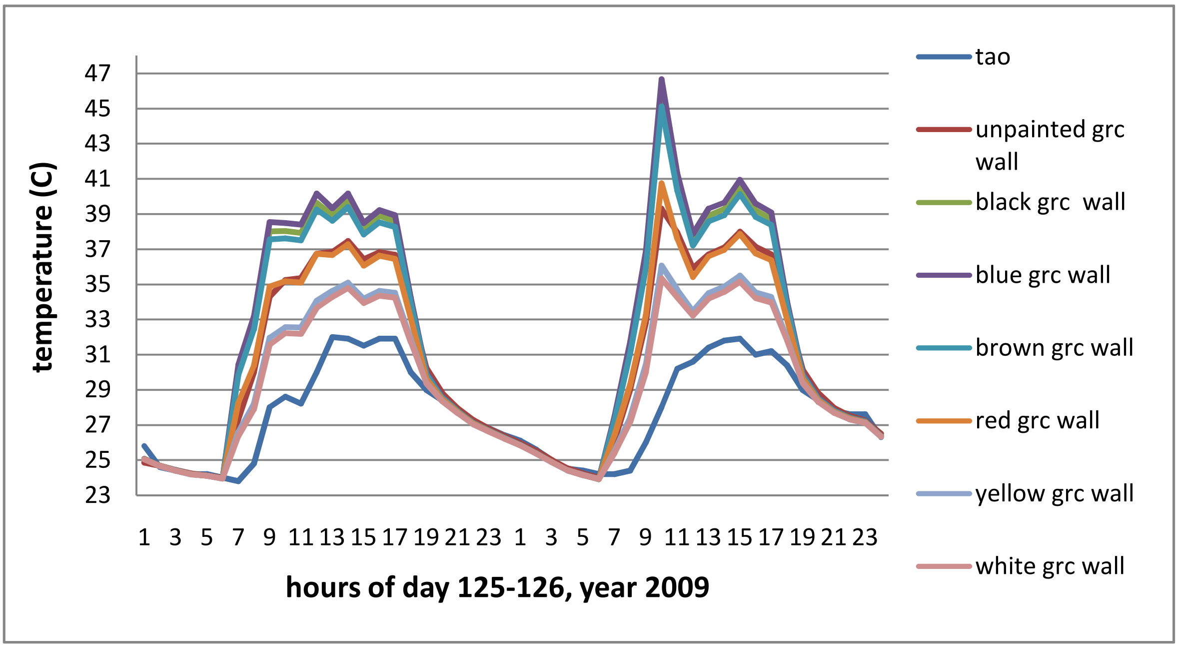
Figure 8.19 Influence of painted brick roof upon inside air temperature




| | tao | unpainted zinc roof | black zinc roof | blue zinc roof | Brown zinc roof | shiny black zinc roof | green steel paint zinc roof | red steel paint zinc roof | Yellow zinc roof | White zinc roof | aluminium paint zinc roof |
|---|---|---|---|---|---|---|---|---|---|---|---|
| avg | 27.8 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.8 | 30.6 | 30.7 | 30.5 | 30.6 |
| max | 32.0 | 39.3 | 39.3 | 39.3 | 39.2 | 39.3 | 39.9 | 39.2 | 39.9 | 39.0 | 39.4 |
| min | 23.8 | 24.0 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 24.0 | 23.9 | 23.9 |

Figure 8.20 Influence of painted zinc roof upon inside air temperature

Conversely, by painting the external side of the wall, the inside air temperature is influenced significantly (figure 8.21). The model built from brick wall and zinc roof. Black, brown and blue paint can create a higher inside air temperature which is $6^0$C higher than the outside air temperature. A red painted wall creates the same value of inside air temperature as the unpainted wall. Meanwhile white and yellow painted walls are shown to be able to reduce the inside air temperature down by 3 $^0$C from the unpainted wall. It shows that the lighter colour the lower inside temperature.




| | tao | unpainted grc wall | black grc wall | blue grc wall | brown grc wall | red grc wall | yellow grc wall | white grc wall |
|---|---|---|---|---|---|---|---|---|
| avg | 27.8 | 30.6 | 31.7 | 31.9 | 31.6 | 30.5 | 29.4 | 29.2 |
| max | 32.0 | 39.3 | 45.5 | 46.7 | 45.1 | 40.7 | 36.1 | 35.3 |
| min | 23.8 | 24.0 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 |

Figure 8.21 The influence of wall paint upon inside air temperature

### f. Influence of building insulation upon inside air temperature

In this section the investigation on building insulation is carried out by simulating a simple model built in common light materials namely GRC wall and zinc roof. The thermal insulation materials are provided in TAS software. The model is 6x3m opaque shape using gambrel roof. The various insulation materials are simulated in 100 mm thick to be as part of wall and roof.

Figure 8.22 shows that the brick roof insulated with various insulations cannot reduce the inside air temperature. Both the insulated and the bare brick roofs create the high inside air temperature which are up to 37$^0$C, by 5$^0$C higher than the outside value. This result is quite similar to the case shown by TAS in table 6.2. The models used the roof constructions with 3mm thickness of single zinc sheet (outer) and 3mm thick plywood (inside) with 100 mm insulation in between. In general Table 8.2 shows that there are also almost no significant differences in inside air temperatures reduction by using the other insulation materials. Among these insignificant values, mineral wool board + one coat paint and polystrene, expanded are shown to give slightly the lowest inside air temperature. It is by 1.6$^0$C lower than the uninsulated zinc, nevertheless it is still by 5.7 much higher than the outside air temperature.

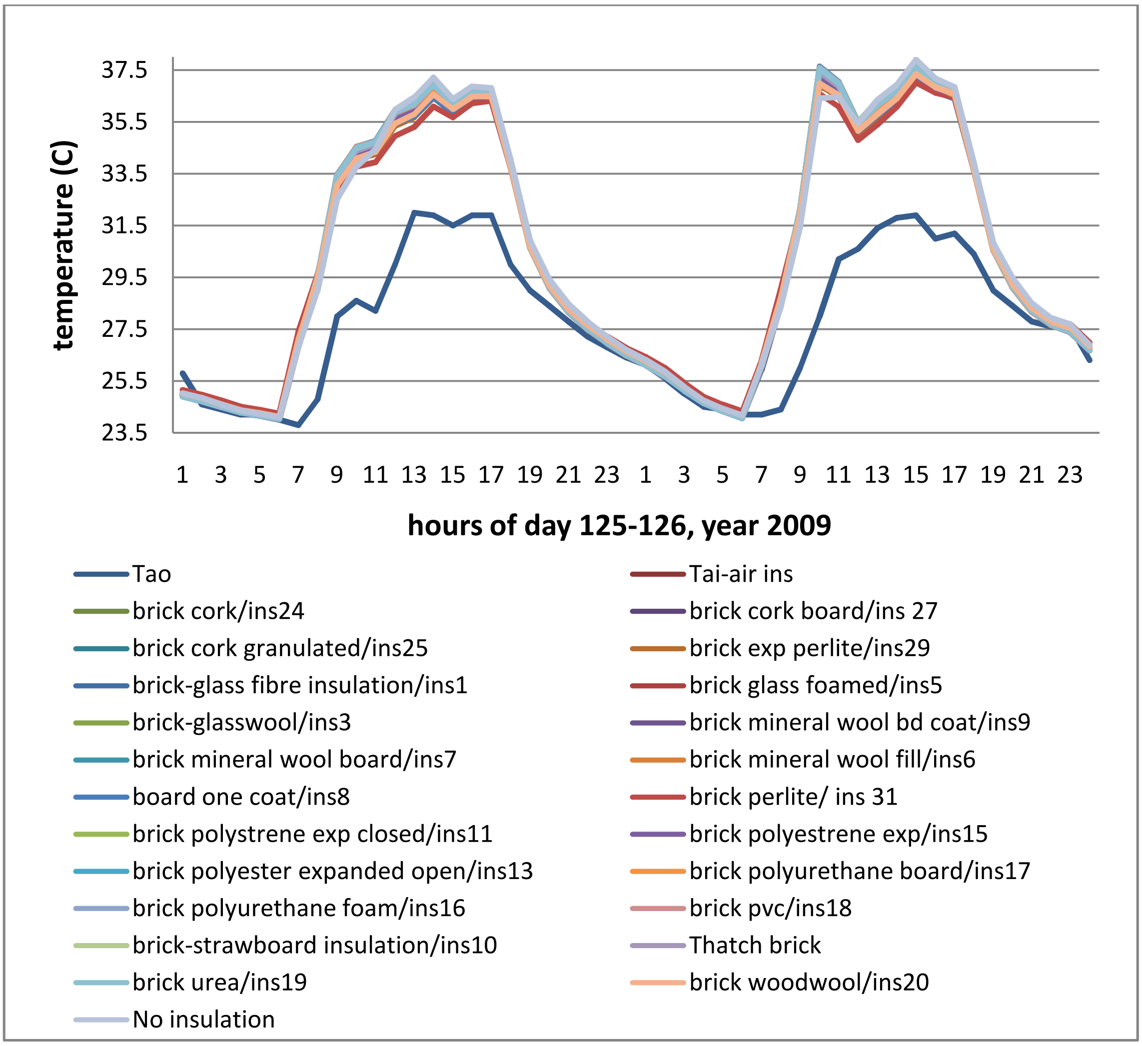



Figure 8.22 Influence of the use of insulations located beneath the brick roof upon inside air temperature

Table 8.2 influence of the use of insulations located beneath the zinc roof upon inside air temperature

| INSULATED ROOF MATERIALS | INTERNAL HORIZONTAL U-VALUES (W/m2K) | temperature (C) | | |
|---|---|---|---|---|
| | | avg | max | min |
| tao | | 27.8 | 32.0 | 23.8 |
| Mineral wool board + one coat paint *2 | 0.422 | 30.4 | 37.7 | 24.1 |
| Polystrene, expanded *2 | 0.276 | 30.4 | 37.7 | 24.0 |
| Cork board 1 *4 | 0.359 | 30.4 | 37.8 | 24.0 |
| Expanded perlite 1 *3 | 0.584 | 30.4 | 37.8 | 24.1 |
| Polyurethane board *3 | 0.233 | 30.5 | 37.8 | 24.0 |
| Mineral wool bd/1 coat polyvinyl acetate *2 | 0.422 | 30.4 | 37.8 | 24.0 |
| Mineral wool board *4 | 0.422 | 30.4 | 37.8 | 24.0 |
| Cork *2 | 0.367 | 30.4 | 37.8 | 24.0 |
| Mineral wool, fill type *3 | 0.351 | 30.5 | 37.8 | 24.0 |
| Cork granulated 1 *2 | 0.407 | 30.5 | 37.8 | 24.0 |
| Glass foamed *1 | 0.399 | 30.5 | 37.8 | 24.0 |
| Woodwool slab 1 *1 | 0.563 | 30.4 | 37.8 | 24.0 |
| Pvc, expanded *2 | 0.399 | 30.5 | 37.9 | 24.0 |
| Polyurethane, foamed *3 | 0.242 | 30.5 | 37.9 | 24.0 |
| Perlite 3 *2 | 1.338 | 30.5 | 37.9 | 24.1 |
| Urea formaldehyde, foamed *3 | 0.293 | 30.5 | 38.0 | 24.0 |
| Aluminium foil | 3.513 | 30.7 | 38.1 | 24.1 |
| Polystrene, expanded, open cell *3 | 0.302 | 30.5 | 38.2 | 24.0 |
| Glasswool 1 *2 | 0.351 | 30.5 | 38.3 | 24.0 |
| Polystrene expanded sheet closed cell *4 | 0.359 | 30.5 | 38.4 | 24.0 |
| Glass fibre 1 *3 | 0.359 | 30.5 | 38.5 | 24.0 |
| Thatch | 0.584 | 30.5 | 38.5 | 24.0 |
| Strawboard *3 | 0.779 | 30.6 | 38.8 | 24.0 |
| 100mm air (upward flow) | 1.428 | 30.6 | 39.0 | 24.0 |
| No insulation | 3.736 | 30.6 | 39.3 | 24.0 |

Another simulation is run by locating the insulation in the middle of the external wall (table 8.3). The wall is composed of 10 mm thick double GRC boards with 100 mm cavity in the middle filled by various insulations. In contrast the result shows the lower internal temperature compared with the result of using the insulation beneath the roof. Among these various insulations, mineral wool board + one coat paint can reduce the air temperature to the lowest degree of $30.4^{0}$C which is lower by about $1.6^{0}$C than the peak outside air temperature.

In daily applications, double GRC boards with the air fill Cavity are the mostly common wall composition. However in this simulation it shows that such application does not bring a better value. It is even worse and higher by about 1.3$^0$C than the peak value of using only single GRC board without any insulation. This is also the worst wall composition which raises the peak inside temperature up to 40.3$^0$C, that is higher by 8.3$^0$C than the peak outside air temperature.

Table 8.3 Influence of the use insulation located inside the wall upon inside air temperature

| INSULATED WALL MATERIALS | INTERNAL HORIZONTAL U-VALUES (W/m2K) | temperature (C) | | |
|---|---|---|---|---|
| | | avg | max | min |
| tao | | 27.8 | 32.0 | 23.8 |
| Mineral wool board + one coat paint *2 | 0.42 | 27.7 | 30.4 | 24.7 |
| Polystrene, expanded *2 | 0.275 | 27.5 | 30.6 | 24.4 |
| Glass fibre 1 *3 | 0.357 | 27.7 | 30.8 | 24.5 |
| Cork board 1 *4 | 0.357 | 27.7 | 30.9 | 24.4 |
| Mineral wool bd/1 coat polyvinyl acetate *2 | 0.42 | 27.8 | 31.1 | 24.5 |
| Mineral wool board *4 | 0.42 | 27.8 | 31.1 | 24.5 |
| Expanded perlite 1 *3 | 0.579 | 28.0 | 31.1 | 24.7 |
| Cork *2 | 0.365 | 27.8 | 31.1 | 24.3 |
| Polyurethane board *3 | 0.233 | 27.6 | 31.3 | 24.1 |
| Polyurethane, foamed *3 | 0.241 | 27.6 | 31.4 | 24.1 |
| Mineral wool, fill type *3 | 0.349 | 27.8 | 31.4 | 24.2 |
| Woodwool slab 1 *1 | 0.558 | 28.0 | 31.5 | 24.5 |
| Urea formaldehyde, foamed *3 | 0.292 | 27.8 | 31.6 | 24.1 |
| Polystrene, expanded, open cell *3 | 0.3 | 27.8 | 31.7 | 24.1 |
| Glass foamed *1 | 0.396 | 27.9 | 31.7 | 24.2 |
| Cork granulated 1 *2 | 0.404 | 27.9 | 31.8 | 24.2 |
| Glasswool 1 *2 | 0.351 | 27.9 | 32.0 | 24.1 |
| Polystrene expanded sheet closed cell *4 | 0.357 | 27.9 | 32.1 | 24.1 |
| Perlite 3 *2 | 1.311 | 28.7 | 32.6 | 24.9 |
| Thatch | 0.579 | 28.3 | 32.9 | 24.1 |
| Strawboard *3 | 0.777 | 28.6 | 33.5 | 24.1 |
| Pvc, expanded *2 | 0.396 | 28.3 | 33.6 | 23.6 |
| 10cm aluminium foil | 3.329 | 30.0 | 34.9 | 25.0 |
| Single grc-no insulation | 3.736 | 30.6 | 39.3 | 24.0 |
| 100mm air (upward flow) | 2.069 | 30.5 | 40.3 | 23.9 |

From the previous two tables we see that the use of insulation in the wall works much better compared with the insulation located beneath the roof. Figure 8.23 shows the use of mineral wool board + one coat paint as the best insulation for the tropical case provided in TAS building simulation software (referring to table 8.2 and 8.3). By carrying out the same models and the same outside weather data, TAS shows that by locating the insulation in both wall and roof, it will work effectively to reduce the peak inside air temperature. It can be decreased by $9^0$C from the inside air temperature in the model without any insulation, which is lower by about $4^0$C than the outside air temperature.

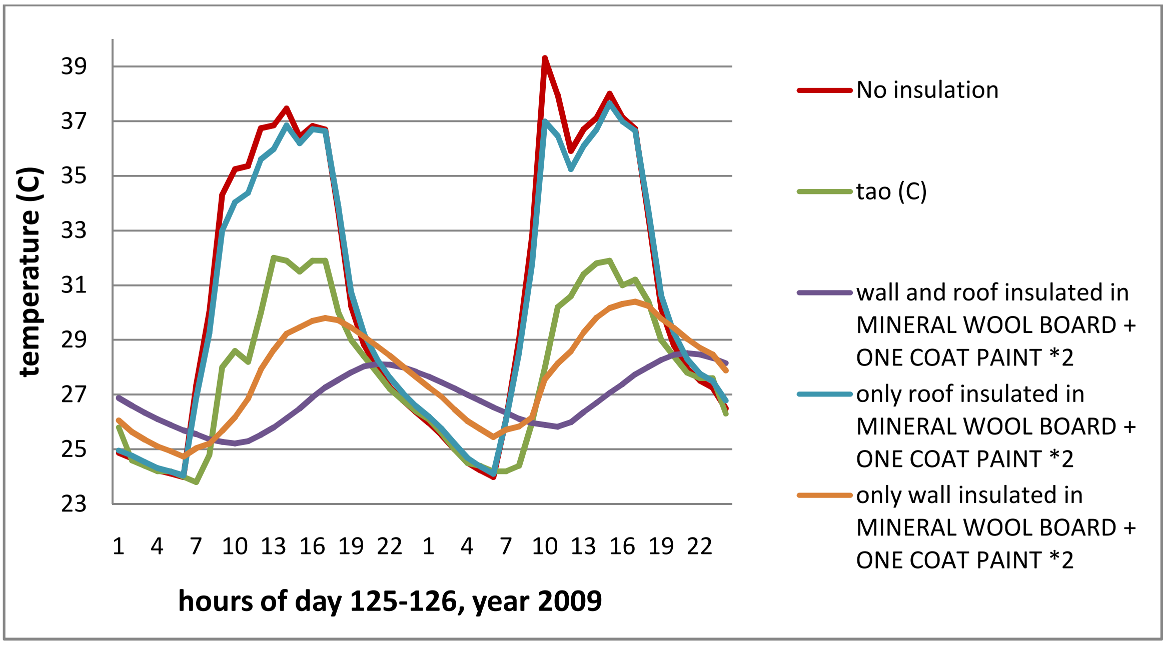



Figure 8.23 Influence of insulation position upon inside air temperature

## 8.3 Discussion of the Proposed and Simulated Building Design Variables

This section summarizes the study on house design variables through simulations on several simple models. As the basic design, low opaque room without any apertures built in high thermal mass building construction can produce low inside air temperature which can be up to $2^0$C lower than the outside air temperature during the day. It is actually the overall aim of building house in tropics. However from the general result we see that the more openings the closer the inside air temperature is to the outside value. Since providing openings or apertures is a quite vital in house design, some other house design variables and relevant literatures are discussed.

**i. Shape**

a. Building houses with apertures should consider a higher ceiling to cool down the inside air temperature. A higher ceiling can reduce the energy use, since it has smaller vertical temperature gradients once the zone is occupied. From the numerical calculations, a higher ceiling will allow greater ventilation therefore allowing the room to meet thermal comfort level (Hashimoto et. al., 2009)

b. Allowing a wider floor area can decrease the inside air temperature, and can be approached by minimising the number of inside partitions or internal walls. Such an approach also allows the air to flow throughout the house layout and hence reduce the inside air temperature. Traditional houses in Japan apply this method by having an open-plan lay out with large windows through which air moves across rooms (Iwashita et. al., 1998). Such design is also recommended to be applied in houses in Thailand (Tantasavasdi et. al., 2001).

c. There is no significant influence of building form i.e circle, square etc in reducing the inside air temperature. The significant thing to get lower air temperature is by minimising the surface area exposed to the outside solar radiation.

d. In a tropical climate, it is not suitable to apply a flat roof since it can give the highest hence the worst inside air temperature. Gambrel, hip and gable roofs are recommended for use in tropical areas. Among these three, the gable roof is slightly better in providing the lower inside air temperature.

e. Grounded house or detached house can contribute to cooling down the inside air temperature. Conversely, based on TAS simulation, the raised floor house can give a higher inside air temperature because the outside raised floor is also allowed to be indirectly heated by the sun. The reason why most traditional houses in tropics are built with a raised floor is to protect the houses from wild animal attacks and flood. Therefore in order to produce a lower inside temperature in raised floor dwellings, the building materials, shadings and apertures are among the other significant design variables that need to be considered. Apertures are not only applied on the wall but also on the floor. Typically, the raised floor traditional house has floor boards with gaps to let the air to circulate in and out from beneath the building, allowing a reduction in the inside air temperature. This is also applied in traditional Malaysian house (Tahir et. al., 2010)

**ii. House orientation**

Considering house orientation toward the sun in building houses will contribute the low inside air temperature. Orienting the long sides or the openings of the house to north and south can avoid the direct sun radiation during morning and afternoon and hence get lower inside air temperature during the day. Meanwhile, orienting the house to north-east and north-west gives slightly higher inside air temperature compared with the one in orienting to north and south. However it is slightly better than facing the house totally to east and west. Other studies found that building with shallow rooms elongated from east to west and facing north in the hot and humid tropics, performs better in achieving comfortable indoor conditions (Hyde, 2000).

**iii. Ventilation and Shading**

In the warmer climate ventilation plays an essential role in reducing the inside air temperature. In spite of contributing the high internal thermal performance due to the solar penetration, there are several ways to use the ventilation optimally to reduce the inside air temperature:

a. Minimise the unshaded opening area. Enlarging the area of apertures such as windows without any considerations of orientation and the use of shading will create an inside air temperature closer to the outside value. It is even higher once combined with inappropriate wall material. Opening the aperture must be well managed to obtain the lower internal thermal performance. During the day, since the outside air temperature reaches its highest values, it is much better to shade the apertures properly during the day to avoid heat transmission. While responding the heat trapped and released into the house during the night due to the use of thermal mass building materials can be solved by using night cooling. That is by opening window during the night to let the air flowing in and hence reducing the inside air temperature.

b. Locate the openings to face the prevailing wind. Wind speed does reduce the air temperature. According to Kammerud et. al., (1984) the openings will create a higher ventilation rate which can reduce the cooling energy use in residential buildings. Based on their tentative calculation for the model building, the cooling load reduction increases by 35% as the air change rate increases from 3.3 to 17 per hour in the warmer climate.

c. Shade all the exposed walls and openings to prevent unnecessary heat transfer into the house. One of the benefits of shading can be seen from the use of a balcony. It can increase air velocity and improve the indoor comfort level under standing activity (1.25 met), while for seated activity the environmental condition was rated as slightly cool acceptable (Prianto et. al., 2002).

d. Use window configuration to achieve the low inside air temperature. Prianto et. al. (2002) studied the effect of window configuration. They conclude that pivoted windows with angle $45^0$C can increase air speed and hence improve the comfort level; In tropical humid climate using pivoted window in downward position with angle >$45^0$ is more applicable to reduce the internal air temperature; Using various blind angles of 60-$90^0$ can reach the comfort level for activity 1.25 met; Louver windows at the ceiling height and floor level with angle of $45^0$ achieve a comfortable condition under activities of 1 and 1.25 met.

**iv. Building Materials**

**a. Wall materials**

Using light weight materials for wall construction in tropical areas is mostly recommended in the literature. TAS also indicates that such construction will give a lower value of dissatisfied vote of occupants. This may be due to the lower inside air temperature close to the outside value brought by such construction during night and very early morning. Nevertheless, a light weight wall construction will give a very high inside air temperature that can be higher by $6^0$C than the peak outside air temperature. Therefore applying the light weight material must be considered to be located indirectly to sun radiation or to be fully shaded.

Currently, heavy weight wall construction is a preferable house trend in Indonesia which is also applied in post tsunami housing. TAS shows that this building construction can reduce the peak outside air temperature by $1^0$C during the day. This may be the reason most the tsunami victims chose such construction, apart from the more rigid and strong performance. However the night and the very early morning inside air temperature is higher than the outside value due to the thermal mass character. It is also believed to be the reason that occupants in such house construction mostly use air conditioners during the evening until the following morning. Such problems can be solved by using night cooling system and use of shades to minimise the wall exposure to the sun. With respect to the thermal mass characteristic, Wonorahadjo et. al. (2008) suggest that the hot heavy weight material should be positioned horizontally such as floor, pedestrian way, or street.

**b. Floor materials**

The most typical floor materials used in tropical areas are cement and ceramic tile floor. These materials can work as cooling floor. Between these two, the ceramic tile floor is shown to have a slightly better performance in reducing the inside air temperature, which is about $0.2^0$C lower than the cement floor can give.

**c. Roof materials**

The roof is the house surface facing the sun directly in tropical latitudes. Since the heat conducted into the building is coming from the sun, designing the roof in the correct way may reduce the inside air temperature. The use of a cooling roof is highly required in order to achieve low indoor temperature in tropical climates, yet such roof construction is not familiar in Aceh or not even in the whole of Indonesia. Thatch used to be applied as roof material in most Indonesian traditional houses. Meanwhile the currently common roof materials have been shifted to be clay tile roof and metal roof such as zinc and aluminium. In this study thatch is proved to be the best cooling roof material among clay tile, metal and brick roof.

An ideal exterior surface coating for a cooling-dominated climate would have reflectance near 1.0 and infrared emissivity near 1.0, so that absorbed heat is radiated back to the sky. White plaster very nearly achieves this combination.

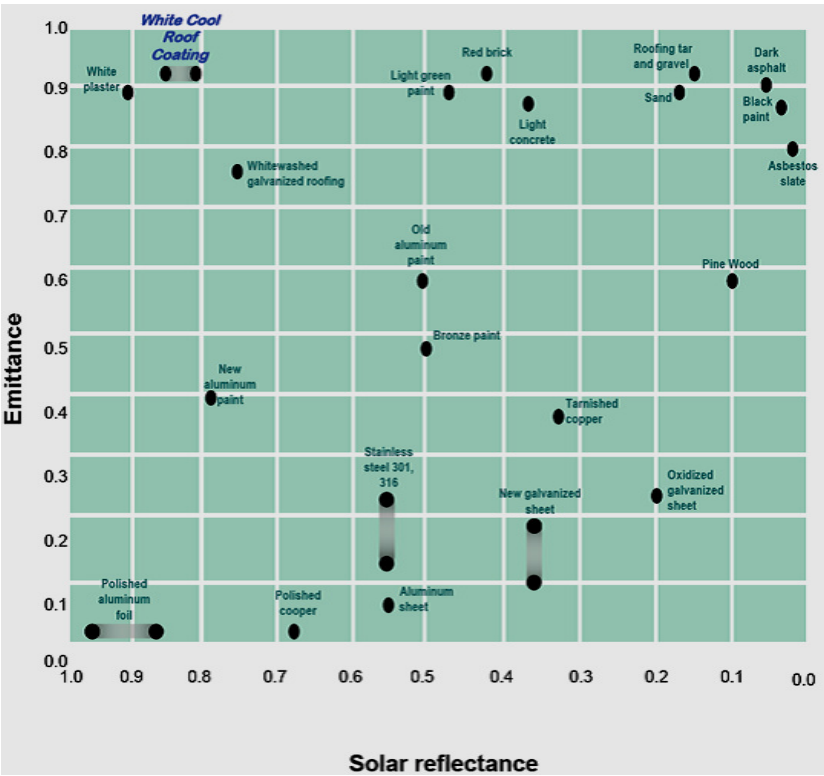



Figure 8.24 Spectral characteristics of building materials, (Source: protek-usa, 2011)

Polished aluminium foil has a very high solar reflectance, but its emissivity is low, so it retains heat. This may be the reason for high inside air temperature in some post tsunami houses that use aluminium foil as the insulation. A bare surface metal roof will give a severe indoor climate therefore it is recommended to be coated or painted as a very simple way to solve the problem, yet we must also consider the use of materials performing cooling load reduction, which have both high albedo and high emissivity. Considering the use of a cooling roof can help increase roof life, because the roof temperature is more constant. The thermal stress of conventional roofs can expand and crack the roofing material, but because cool roofs stay cooler on hot sunny days, they expand and contract less and should therefore last longer than conventional roofs (USAID, 2003). Reducing the inside air temperature can also be approached by the use of clay or concrete with low concentrations of light absorbing impurities, such as iron oxides and elemental carbon[1].

There are some cooling roof configurations that can be applied in tropical climates. Ben Cheikh et. al. (2008) studied a passive cooling roof in a hot arid area. The passive cooling roof is composed of a steel plate ceiling and a flat aluminium plate separated by an air space partially filled with high thermal capacity rocks placed in a small quantity of water. The system is properly closed to prevent water vapour escaping outside (figure 8.23). The result is that the evaporative reflective roof can reduce the internal room air temperatures during the day up to 10 °C in comparison to the air temperatures for a bare roof over the room.

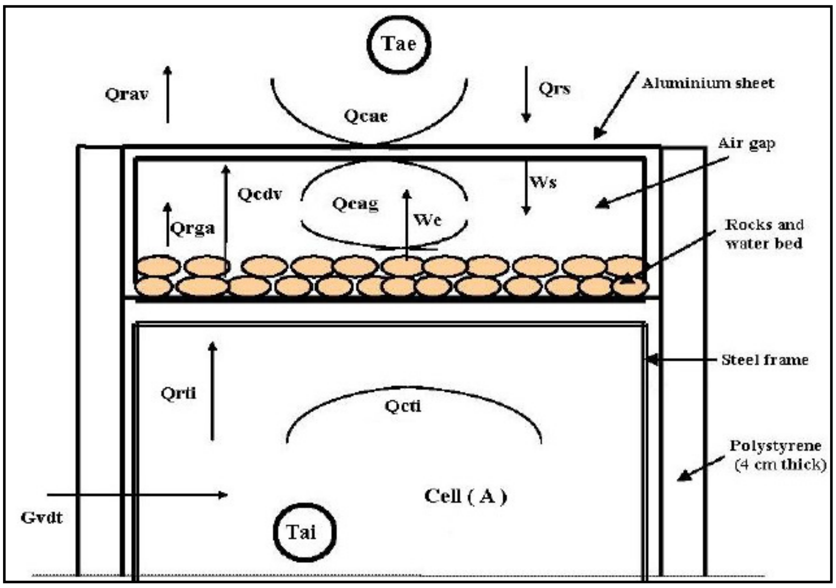


Figure 8.25 A schematic diagram of the model design (Ben Cheikh et al., 2008)

[1] http://HeatIsland.LBL.gov/

Another roof configuration is such as green roof using planting either intensive or extensively to cool the inside room. Green roofs have been studied widely and are well known to work successfully in any climates in giving comfort air temperature.

### d. Material colours

Coating the building surfaces with light colours is very beneficial in cooling down the inside building. From the previous section carrying out the simple simulation, we can recognize that painting the wall in light colours such as white and yellow will help to reduce the inside air temperature. Lighter colours on the wall will decrease the inside air temperature about by $2^0$C from the value by using unpainted wall. In contrast, the use of dark colours may create very high inside air temperatures. It is higher by about $2^0$C than the value with an unpainted wall and even higher by about $6^0$C than the outside air temperature.

Meanwhile, in this study TAS shows that painting the roof in any colours does not appear to reduce the inside air temperature significantly. In general, roofs painted in any colours gives temperatures just as high as the value with an unpainted roof. However the slight differences in that case show that a light colour such as white is also mostly able to reduce the air temperature lower than any dark colour. As the heat from sun faces the roof directly, colouring the roof must be also treated specially to get it work effectively. White roof is also actually recommended by many scientist to reduce the inside air temperature. Emmanuel (2010) through his study found that white roof/ roof insulation combination can reduce indoor air temperature up to $3^0$C.  Keith Oleson, the lead author of the study and a researcher at the National Center for Atmospheric Research (NCAR) in Boulder, Colo also said that white roof is an effective roof in reducing the effect of urban island (Life Science, 2010). As it has a great benefit, Professor Steven Chu, the US Energy Secretary, President Obama's energy adviser has suggested all the world's roofs should be painted white as part of efforts to slow global warming; it would save energy and money on air conditioning by deflecting the sun's rays (Gray, 2009).

### f. Insulation

In the tropics the use of thermal insulation is not common compared with in cold climates. Nevertheless, regarding the simulation results explained in the previous section, we can see that combining mineral wool board + one coat paint or polystrene, expanded as wall insulation with GRC wall can reduce the inside air temperature lower by $2^0$C than the outside air temperature. However while it is fitted beneath the roof the reduction is not significant at all. It only reduces the air temperature by $1.6^0$C for the uninsulated roof yet still higher by $5.7^0$C than the outside air temperature. The lowest inside air temperature during the day is achieved by insulating the wall and the roof. The reduction can be by $4^0$C lower than the outside air temperature.

Aluminium foil is the most common insulation used in post tsunami houses, located beneath the roof. In this study, it shows that such construction does not give the significant low thermal performance. As previously mentioned, it does so since aluminium foil has a very high solar reflectance, but its emissivity is low, so it retains heat.

**v. Environment**

The environment has a large influence in reducing the inside air temperature; especially with air movement supply dealing with cross ventilation. In this study, this is not simulated and broadly investigated. However, there are lots of studies prove that the environment has the great influence in providing lower inside air temperature (Emmanuel et. al., 2007; Tantasavasdi et. al., 2007). Untreated environment may lead to even larger effect such as Urban Heat Islands (UHIs). In dealing with this using lighter colours on all man-made surfaces (i.e. roofs and walls in white, and light-coloured concrete paved road); increase the green cover within the street canyon by planting 10 m high trees with distinct crown, at 20 m interval along the street; and increase the shading level at neighbourhood scale will help to mitigate the environments in tropic which consequently may reduce the indoor air temperature (Emmanuel et. al., 2007). Tantasavasdi et. al. (2007) added that the environment covered with large trees can give a higher average temperature drop than the others, especially during the hottest hours of the day. It represents the best type of arrangement, which is better than those covered with small trees and grass. A hard surface represents the worst environment.

## 8.4 Responds toward the use of TAS

The study using TAS to simulate the building design variables in this chapter provides insight into the potential and limitations of TAS. This study shows that building materials are considered by TAS quite well, as shown by the inside air temperature resulting from the use of various building materials. TAS also specially considers the materials, colours and insulation assigned to the wall, as shown by the significance of the inside air temperatures resulting from the use of various wall materials. However, TAS does not model correctly the reduction in inside air temperature when insulation is used on the roof. This also happens to the zinc roof painted in white, which is predicted by TAS to have no impact on reducing the inside air temperature. TAS only considers the light colours to be effective in cooling down the room by assigning it to the external surface of the brick roof instead of the zinc roof. Also thermal stratification in a high ceiling is not modelled correctly by TAS.

The limitations of TAS suggest that designing guideline for a good house responding the tropical climate should consider any previous studies and the field measurement rather than relying mainly on TAS prediction. The measured results provide a more robust estimate of thermal comfort than those modelled. Relying for the building design purely on TAS may only consider the effect of building materials yet neglect some other building design considerations.

# CHAPTER 9 – RECOMMENDATIONS FOR HOUSE BUILDING DESIGN IN POST TSUNAMI AREAS IN A TROPICAL CLIMATE

## 9.1 Introduction

This chapter finalizes this study by giving building recommendations based on the results of the work in the previous chapters. The recommendations are steps towards environmental-friendly performance and sustainable housing. They are based on analysis of the questionnaire answers; the thermal measurements and the simulations on some post tsunami house models carried out using TAS thermal building simulation software; and some supporting literatures. Following up the indoor thermal comfort assessment, alternative house designs focusing on the house model that can provide low inside air temperature are proposed. Prices of wall and roof where the variations of designs are applied are also estimated.

## 9.2 Recommendations for House Building Design in post Tsunami Areas in a Tropical Climate

There are actually various guidelines dealing with house design in the tropics either used in post disaster area (UNEP, 2007; Aceh Building Code, 2005) or vice versa (Larasati, 2006). In this study the proposed recommendations are carried out from the conditions (based on the questionnaire) mostly occurred when the houses were occupied.

A. House design

- ✓ Give initial advice to the tsunami victims about the suitable, safe and therefore sustainable house responding to their house site condition before deciding which house types will be built for the tsunami victims. Thereafter, give them right to select which house types they prefer from the proposed types. This is the way to avoid the conflict that may occur afterward causing them to reject occupation of the house, leading to the wasting of large amounts of money.

- ✓ Provide minimum house area that can accommodate the essential rooms such as one living room, two bed rooms, one kitchen and one toilet. $45m^2$ is proposed to be better than $36m^2$ as the currently recommended one which cannot accommodate kitchen and toilet.

B. House materials

- ✓ Use sustainable building materials based on the following criteria:
  - Materials from renewable sources such as wood, bamboo from replanted forest
  - Materials from local sources as to cut back on energy and transportation costs
  - Use local labour to conduct the reconstruction to cut back costs.

Once these criteria are met, a large amount of such materials are needed to get through the gigantic reconstruction hence these actions are further recommended:

- Be responsible with the surrounding area of the excavated local sources which highly affect local people
- Train the local people involved in workmanship in the reconstruction process to maintain the good quality of the houses.

- ✓ Use materials that contain no toxic chemicals
- ✓ House material is highly related to house construction. House construction in post disaster area pays serious attentions to the avoidance of house collapse due to structural strength problems. However the house structure is not the main objective of this study since it has been broadly discussed and concerned through several of house construction guidelines in the case of the tropics. Therefore for the house guidelines covering the house structure and construction issues are directly linked to these following sources:
  - ***UN Habitat,*** *Construction guidelines*: contains the construction guidelines compiled from field experience and recommendations from building experts. This guideline is applicable to be used in earthquake-vulnerable areas such as Aceh.
  - ***ARUP,*** *Aceh and Nias Post Tsunami Reconstruction, Review of Aceh Housing Program*: contains the findings of a field trip and guidance for the rebuilding

process following the 26 December 2004 earthquake and tsunami, on behalf of Muslim Aid to the Aceh Province, which was made by Jo da Silva and Zygmunt Lubkowski from Arup, between 20 February and 3 March 2006.

- ***Building Codes, NAD***: contains the building guidelines applicable for Aceh (NAD) area. The guidelines refer to the Indonesian building standard (SNI)

C. Thermal comfort

✓ Recommendations on how to provide indoor thermal comfort are explained in chapter 8.3

D. Lighting

✓ Provide sufficient openings in each room to let the daylight work during the day optimally. Yet, the aperture should consider the position against the direct sunlight as discussed in chapter 8.3.

✓ Promote the benefit of daylight, so that the beneficiary will consider it once they do some house extensions with their own financial and effort.

✓ Advise the beneficiary to use energy saving lighting during the night or if needed during the day.

✓ Use solar-powered lights broadly as a step towards sustainable living. As currently this is not commonly used in housing case, the participation of the government is highly needed to implement it. The electricity in Aceh is still a problem that is caused either by the limited provision to the houses or the limited power generating the electricity itself causing the light to be frequently cut. Therefore in Aceh or any tropical areas where sunlight is quite abundant, solar-powered lights may be the best option to light post disaster houses for any future disaster.

E. Noise

As the most common house type built in Aceh is single house or one storey house, noise is currently not a major problem. Nevertheless, since from the questionnaire the small number complaining about noise noticed that the noises were from outside such as vehicles, children's voices playing outside and construction works, while the inside noise was mostly caused by appliances switched on in high volume; therefore some actions need to be considered in future post disaster houses where traffic is likely to be present. The actions are as follows:

- ✓ Fit a barrier to the side of the house directly facing the street with such as heavy high bushes or fence that can protect the house from outside noise. Fitting the insulated wall against the noise that is commonly applied in western countries may not be suitable in Aceh or tropic area where the buildings are designed to be naturally ventilated. Using an insulated wall may require a totally sealed house whereas naturally ventilated houses in tropic are advised to have more apertures to let the air circulate and cool the house.

F. Environmental/ surrounding assessment

- ✓ Build houses with consideration for natural disasters that commonly attack such as earthquake and flooding. Consideration should be made of the type of soil and house construction. This is also linked to the previous building guidelines such as ***UN Habitat,*** *Construction guidelines;* ***ARUP,*** *Aceh and Nias Post Tsunami Reconstruction, Review of Aceh Housing Program; and* **Building Codes, NA.**

- ✓ Green the house surroundings by planting fully shaded vegetation to reduce the air temperature.

- ✓ Avoid the excessive use of concrete or hard surfaces, due to their inability to absorb rain water, worsening the conditions during the rainy season

G. Water and waste treatments

- ✓ Integrate the house design with the clean water supply; drainage provision; and waste/ garbage/ sewage treatment

- ✓ Provide water tight-septic tank to reduce the contamination of groundwater by using a sustainable system such as vegetated-leach field. No details of sanitation systems are discussed in this study. The more detailed system can be seen in: *GTZ, 2007. Guidelines for the Selection and Implementation of Sustainable Sanitation Systems for the Reconstruction in Aceh and Nias.*
- ✓ Employ a sustainable garbage treatment such as by recycle and reuse; or at least collect garbage frequently, carried out either by government or private sector to avoid irresponsible manner of the community in treating the garbage

H. Access to local public facilities (between 500 m- 1 km from the neighbourhood)

- ✓ Consider the access to local facilities in walking distance in building large scale housing
- ✓ If walking distance-public facilities are not accessible, direct the public transport to the nearest area

I. Health considerations in house design

- ✓ Even though in this study Sick Building Syndrome has not occurred, this issue must be taken into account in order to avoid their occurrence several years after the occupancy time by looking back at the use of safe building materials and proper house design.

J. Energy assessment

- ✓ Integrate the power supply into house design and ensure that the houses are ready for occupation by the people. The unavailability of power is the main reason for people to leave the house unoccupied. Even worse is that this also encourages people to obtain the electricity illegally in a way that endangers their life.
- ✓ Use solar powered lamps as a step to approach sustainable housing as previously explained.

These building recommendations are proposed to be considered in going through the post disaster rehabilitation and the reconstruction applying the Acehnese climate and local people preferences. This study found that by neglecting these considerations, the conventional living condition which is far from the expected sustainability will likely to be continuously applied. The chance to get the people to abandon the houses donated for them is also possible to happen. Apart from post disaster cases, the recommendations are also applicable in any housing developments in Aceh or similar areas. The next following sub chapter presents the house models employing the recommendation of building housing in tropics.

### 9.3 A House model applying the proposed building design variables

In this section, alternative house designs that can reduce inside air temperature are proposed. Based on the review on house design variables in chapter 8, we find out that the heavyweight construction using thermal mass materials needs different treatment from the lightweight construction in providing internal thermal comfort in the tropics.

Therefore this study provides two different house types, namely heavy and light weight houses. Those two models are based on the following house design:

> A simple model consists of two bedrooms, a living room, a kitchen and a toilet. The floor area is $46m^2$. The height of the wall is 3.5m. The house is designed with ventilation between the roof and the ceiling which is fully opened for 24 hours. The large windows are designed in jalousie type which is assumed to be equal to 50% of opening value set up for 24 hours too. The sun shading is 1 meter wide located along the roof and additional 1 meter wide shading is located above the windows. A 2 meters shading located at the front used as terrace roof is also applied. The roof is designed as gable pitch roof with air loft.

The house materials for the two house designs are set up as follows:

Table 9.1 Simulated house materials

| | **U value ($W/m^2K$)** |
|---|---|
| Ground floor | Cemented floor (U- value: 0.49) |
| Shading | Zinc sheet (U- value: 3.85) |
| Window | Glass (U- value: 5.73) |
| Door | Timber (U- value: 1.65) |
| Door and window frame | Timber (U- value: 1.65) |
| Ceiling | Ply wood (U- value: 3.33) |

The wall materials are variously described as follows:

Table 9.2 Simulated wall materials

| **Wall construction** | **U-values** ($W/m^2K$) |
|---|---|
| White painted 15cm diameter bamboo | 0.875 |
| White painted cement plastered brick | 1.37 |
| White painted double GRC sheet insulated with 10 cm mineral wool board | 0.422 |
| White painted single GRC sheet | 3.73 |
| White painted double GRC sheet | 2.17 |
| White painted single plywood | 3.42 |
| White painted double plywood | 1.96 |
| White painted cement plastered 2cm bamboo web | 2.55 |

The simple significant differences of cooling strategies implied in the proposed houses are as follows:

a. Heavy weight house:
   - Due to the use of high thermal mass such as cement-plastered brick that can provide lower inside air temperature, it should have fewer openings and let the openings open during the night to cool the heat released by the building envelope due to the time lag (it refers to figure 8.8; and 8.10).
   - The large windows are only located to face north and south. Meanwhile, the wall sides facing west and east are only fitted with small size openings or ventilators positioned 3 meters above the ground floor. The small sizes of ventilator shaded by the roof overhang are aimed at avoiding the large amount of sun radiation coming into the house and being trapped by the building envelope; yet allowing the air to flow in to the house (figure 9.1).

b. Light weight house:
   - In contrast, the light weight building using materials such as plywood and GRC sheet needs the opposite treatment. The character of suffering very high surface temperature during peak day requires the light weight construction to have lots of openings or apertures to allow the air to move through the house and hence reduce the inside air temperature (it refers to figure 8.8; and 8.9).
   - The light weight house is designed to have more large apertures positioned surrounding the house. 1 meter shadings are applied above the windows (figure 9.2).

The external surface of walls and roof of these two house models are painted in white as recommended in house design variables in chapter 7. Two roof designs are applied. The first one is white painted zinc roof with the U-value of 3.85 W/m$^2$K, while the second one is white painted zinc roof insulated with 10 cm mineral wool board with the U-value of 0.42 W/m$^2$K. The use of mineral wool board as the insulation is selected as it can reduce the inside air temperature effectively (table 8.2) and it is availably sold in Indonesia.

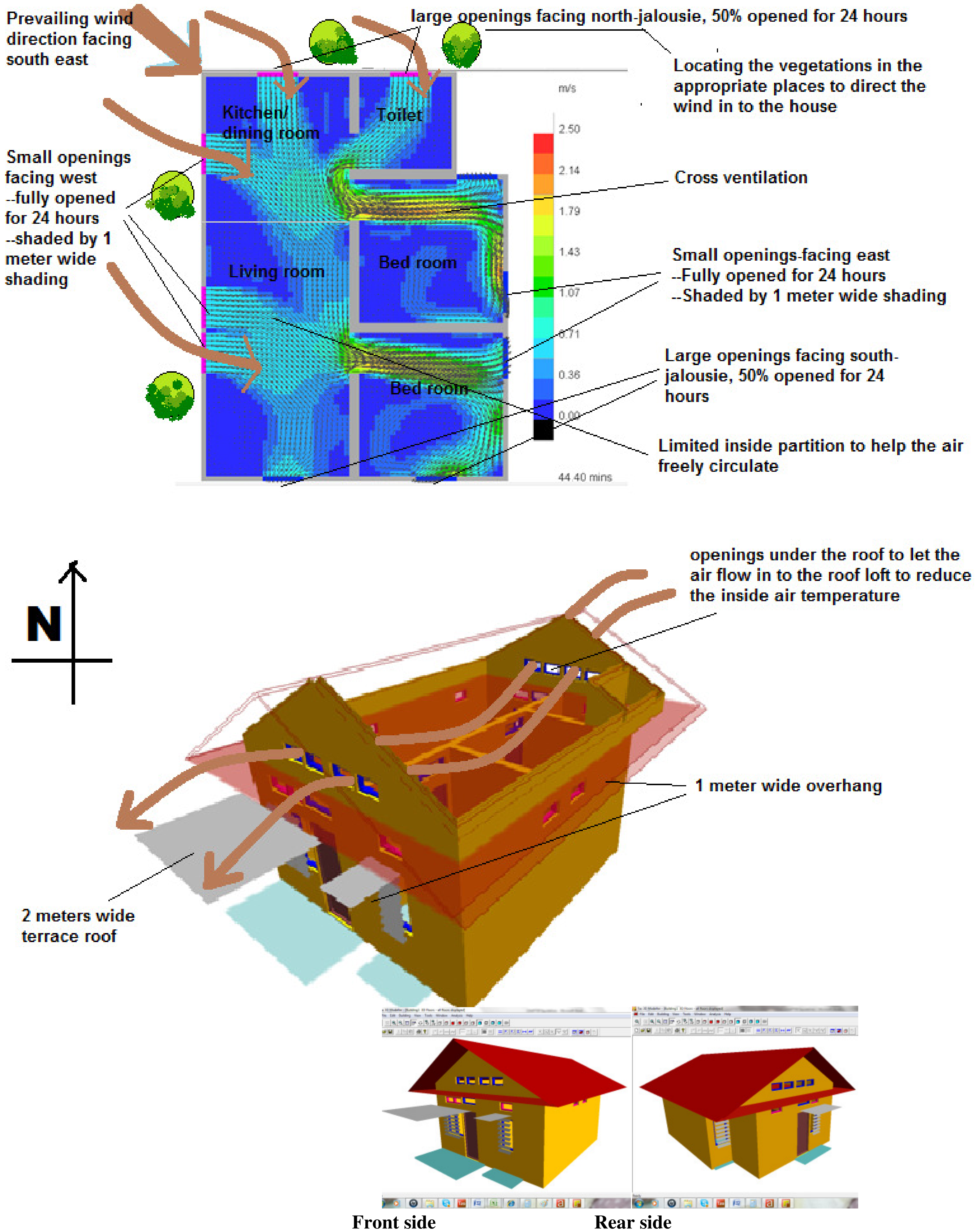



Figure 9.1 The first house design built in heavy weight construction

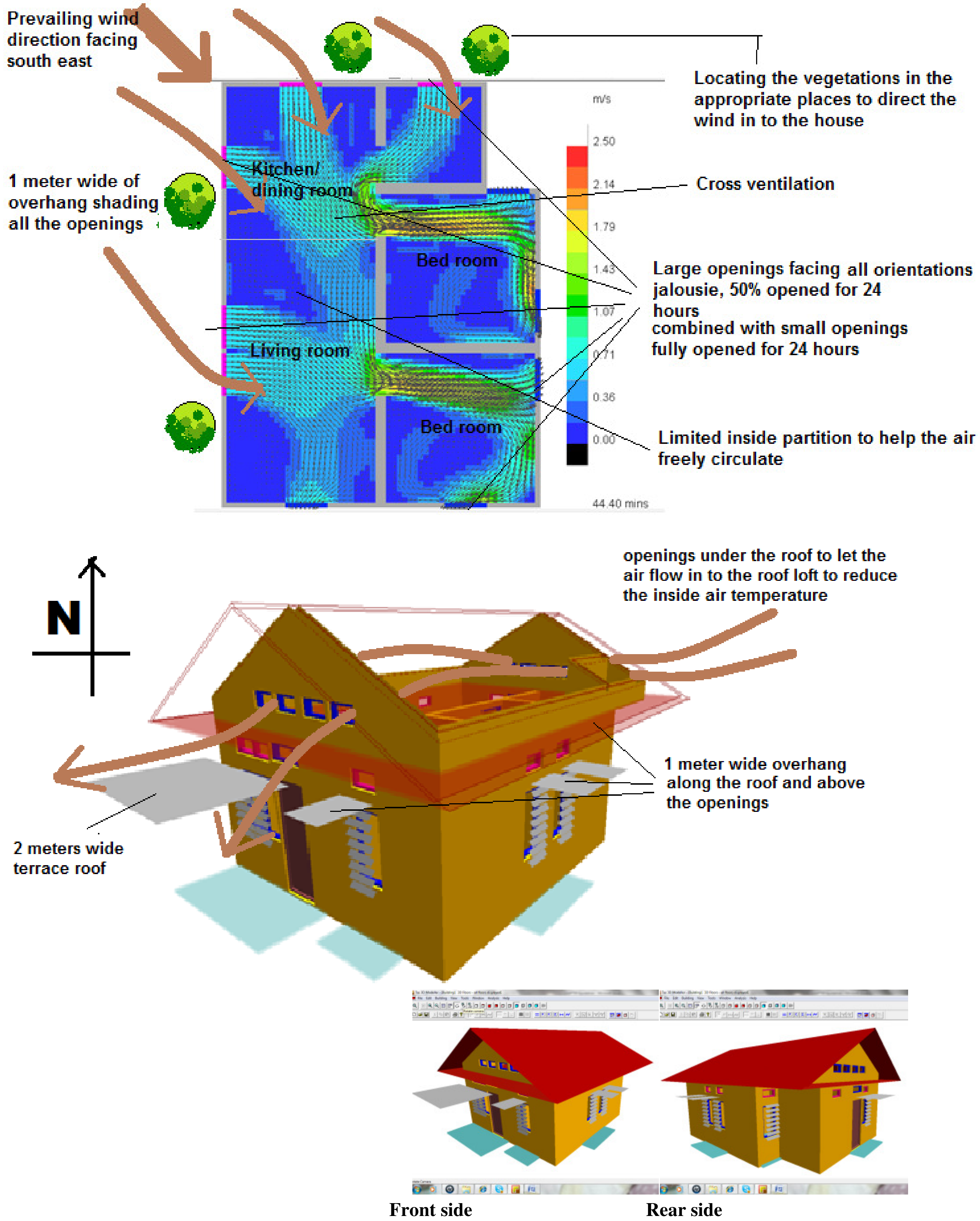



Figure 9.2 The second house design built in light weight construction

These wall constructions are used as those are available and commonly used in Aceh. Bamboo and the GRC sheets insulated with mineral wool board as the alternative wall materials are proposed. As briefly explained in the literature review, bamboo is not a new building material in Indonesia, moreover in Java Island bamboo are currently advised as the sustainable building materials and broadly used in dwelling.

However in Aceh bamboo is not common at all to be used as house materials. Currently it is only used as simple use-public building such as cafe and some house furniture and handicrafts. Nevertheless due to its simplicity in growing in many parts of Indonesia including Aceh and it only takes about three years to get ready to be used as construction materials, therefore it is proposed. Meanwhile GRC sheets insulated with mineral wool board is used since chapter 8 shows that such this construction may reduce the inside air temperature.

The two alternative materials which are categorised as the light weight materials act similarly to the heavyweight. Therefore those two are simulated in the first house design. While the remaining wall constructions are applied in the second house design. By using the weather data of year 2009, the model is simulated. The comparisons of internal temperature are carried out on day 125-126. The predictions of number of hours within a year when people are satisfied with the inside air temperature which is ranged in -1<PMV< 1 are also carried out using TAS macro. Finally, the wall and roof price per m$^2$ are also estimated based on the calculation in appendix C. The following table shows the variations of inside air temperatures provided by using different wall and roof materials.

Table 9.3. Variations of inside air temperatures and wall and roof construction price provided by using different wall and roof materials.

| Building construction | Price per m2 (only : wall construction per m2 + roof sheet per m2) | inside air temperature (C$^0$) in the living room (area 15m$^2$) | | | Temperature difference (tai-tao) (C$^0$) | | | Hours Inside comfort range within a year (%) |
|---|---|---|---|---|---|---|---|---|
| | | avg | max | min | avg | max | min | *-1 < PMV < 1* |
| 15cm bamboo wall + white painted zinc roof * | Rp 116,450.00 | 27.9 | 31.1 | 24.8 | 0.2 | -0.9 | 1.0 | 71.32 |
| plastered brick +white painted zinc roof* | Rp 201,000.00 | 28.0 | 31.4 | 24.6 | 0.2 | -0.6 | 0.8 | 67.79 |
| Double GRC insulated with 10 cm mineral wool board + white painted zinc roof* | Rp 200,750.00 | 28.1 | 31.8 | 24.5 | 0.3 | -0.2 | 0.6 | 69.35 |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 15cm bamboo wall + white painted zinc roof insulated with 10cm mineral wool board ** | Rp 269,200.00 | 27.7 | 30.7 | 24.8 | 0.0 | -1.3 | 1.0 | 75.88 |
| plastered brick + white painted zinc roof insulated with 10cm mineral wool board ** | Rp 353,800.00 | 27.8 | 31.0 | 24.7 | 0.1 | -1.0 | 0.8 | 71.97 |
| Double GRC insulated with 10 cm mineral wool board + white painted zinc roof insulated with 10cm mineral wool board ** | Rp 353,550.00 | 27.9 | 31.6 | 24.4 | 0.1 | -0.4 | 0.6 | 74.76 |
| | | | | | | | | |
| Double ply wood wall + white painted zinc roof* | Rp 134,100.00 | 28.0 | 32.1 | 24.1 | 0.2 | 0.1 | 0.3 | 64.48 |
| Double GRC wall + white painted zinc roof* | Rp 124,100.00 | 28.0 | 32.1 | 24.1 | 0.2 | 0.1 | 0.3 | 64.39 |
| 2cm plastered bamboo+ white painted zinc roof* | Rp 109.600.00 | 28.0 | 32.1 | 24.1 | 0.3 | 0.1 | 0.3 | 64.14 |
| Single ply wood wall + white painted zinc roof* | Rp 109,850.00 | 28.0 | 32.2 | 24.1 | 0.2 | 0.2 | 0.3 | 63.36 |
| Single GRC wall + white painted zinc roof* | Rp 104,800.00 | 28.0 | 32.2 | 24.1 | 0.2 | 0.2 | 0.3 | 63.12 |
| | | | | | | | | |
| Double ply wood wall + white painted zinc roof insulated with 10cm mineral wool board ** | Rp286,900.00 | 28.0 | 32.1 | 24.1 | 0.2 | 0.1 | 0.3 | 66.12 |
| Double GRC wall + white painted zinc roof insulated with 10cm mineral wool board ** | Rp 276,850.00 | 28.0 | 32.1 | 24.1 | 0.2 | 0.1 | 0.3 | 65.88 |
| 2cm plastered bamboo+ white painted zinc roof insulated with 10cm mineral wool board ** | Rp 262,350.00 | 28.0 | 32.1 | 24.1 | 0.2 | 0.1 | 0.3 | 65.49 |
| Single ply wood wall + white painted zinc roof insulated with 10cm mineral wool board ** | Rp 262,600.00 | 28.0 | 32.2 | 24.1 | 0.2 | 0.2 | 0.3 | 66.12 |
| Single GRC wall + white painted zinc roof insulated with 10cm mineral wool board ** | Rp 257,600.00 | 28.0 | 32.2 | 24.1 | 0.2 | 0.2 | 0.3 | 63.98 |

= First house design built in heavy weight constructions

= Second house design built in light weight constructions

* = Using white painted zinc roof

** = Using white painted zinc roof insulated in 10 cm mineral wool board

In general, the use of white painted zinc roof and white painted zinc roof insulated in 10cm mineral wool board work effectively in reducing the air temperature. The total performance of inside air temperatures are lower than the ones measured in some representative of post tsunami houses discussed in chapter 6. More than 63% of number of hours within a year where people are satisfied with the house design (table 9.3).

Table 9.4 Improvement in reducing the inside air temperature using the alternative house design

| Building construction | (Avg) tai in alternatively proposed house design | | | (Avg) tai in real post tsunami house | | | (Avg)improvement in reducing the inside air temperature | | |
|---|---|---|---|---|---|---|---|---|---|
| | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min |
| Heavy weight construction | 27.9 | 31.3 | 24.6 | 30.9 | 33.4 | 28.6 | 3.0 | 2.1 | 4.0 |
| Light weight construction | 28.0 | 32.2 | 24.1 | 31.0 | 35.8 | 27.3 | 3.0 | 3.6 | 3.2 |

Table 9.5 Improvement of hours inside comfort range within a year

| building construction | Average hours inside comfort range within a year (%) [-1<PMV<1] | | |
|---|---|---|---|
| | Alternatively proposed house design | Simulated real post tsunami house | Improvement |
| Heavy weight construction | 71.85 % | 31.63 % | 40.22 % |
| Light weight construction | 64.71 % | 57.7 % | 7.01 % |

The total of hours within a year which is ranged in comfort zone (-1<PMV<1) are better than the ones measured in some representative of post tsunami houses simulated in chapter 7. The proposed heavy and light weight house can be improved to be 71.85% and 7.01% (respectively) within a year to be comfortable (table 9.5).

In this house design (table 9.4), on average it shows that the heavyweight construction can have the lower inside air temperature by $3^0$C, $2^0$C and $4^0$C respectively for average, maximum and minimum compared with those in real heavy weight post tsunami houses. The improvement in reducing the inside air temperature is also achieved by the lightweight house design in this final simulation. The inside air temperature can be reduced by $3^0$C, $3.6^0$C, and $3^0$C respectively for average, maximum and minimum than those in real light weight post tsunami houses. Having $24^0$C as the minimum air temperature that normally occurs during the night and early morning is quite good, because during the hours most of occupants suffer the high inside air temperature due to the absence of air movement and even worse with the released heat trapped by the building envelope. Among the alternative house materials, bamboo is shown to be the best alternative. In spite of the low inside air temperature that it can produce; the price of construction is also cheaper than the other heavy weight constructions.

The average inside air temperature in the alternative house design ($27.9^0$C-$28^0$C) meets the thermal comfort range for Indonesian that is $23.9^0$C-$29.7^0$C (Karyono, 2000). Meanwhile, the maximum air temperature still looks to be higher by $1.6^0$C-$2.5^0$C than the comfort range. However, such remaining degrees are believed to be solved by the ability of Acehnese people to adapt with it by using much lighter clothing. The use of ceiling fan is also recommended to get rid of this.

### 9.4 Conclusion

This chapter has presented the recommendations for house building designs and the proposed house models that can provide lower inside air temperatures as the main point of building design in the tropics. The building recommendations are outlined on house design, house materials, thermal comfort, lighting, noise, environmental/ surrounding assessment, water and waste treatments, access to local facilities in walking distance, health considerations in house design, and energy assessment.

The proposed house models are designed in a simple lay out accommodating the essential rooms, namely a living room, two bedrooms, a kitchen and a toilet. By utilising TAS building simulation software and applying the weather data of year 2009, the models are simulated to presents the predicted annual inside air temperature. The house models use the proposed materials such as bamboo and some other building materials commonly applied in Aceh and apply the house design variables that are presented in chapter 8. The models can provide a lower inside air temperature than the value in post-tsunami houses. These building recommendations and the proposed house models are not only applicable in post-disaster reconstruction but also in any housing developments in Aceh or any similar area. The next chapter is the final stage concluding the research work and recommending some future research.

# CHAPTER 10 – CONCLUSIONS AND RECOMMENDATIONS

## 10.1 Introduction

This chapter summarises the overall stages in this research. The research aimed at assessing the quality of post-tsunami housing was started with reference to a number of sustainable housing concepts. The concepts are relevant as housing is regarded as a very essential thing by disaster victims who lost everything to shelter their lives. As one of the characters of sustainable living is the ability to protect the environment, this study also refers to several factors as assessment parameters utilised in this research, namely indoor thermal comfort; ventilation and indoor air quality; house design including site planning, orientation and building materials; energy efficiency in housing covering household energy use; and environmental issues such as vegetation provision, health considerations in house design and water and waste treatment. The research undertook the assessment through observation, interview/questionnaires and thermal building simulation. Finally, some recommendations including future research related to this thesis are outlined.

## 10.2 Conclusion

As the concluding part of this research, this chapter attempts to provide the brief findings to the research objectives of this study.

- **To assess the conditions in houses built for Tsunami victims with respect to sustainability issues:**

  The overall results show that post-tsunami housing is still built conventionally. It seems that there has been no significant integration between housing construction and house maintenance especially for supporting the occupation stage such as power and water supply; treatment of waste, etc. A lack of knowledge about sustainable living in the community worsens the situation to keep the wheel of life on the conventional track. The excessive uses of local building materials during the reconstruction process have not been followed up in a responsible manner causing damage to the environment. Nevertheless more than 50% of the householders are satisfied with their houses. It is actually quite difficult to find out the real answer to this question, since many householders are very grateful for the houses. For them it is much more comfortable to live in those houses then live in barracks (temporary dwelling), for instance. This study also shows that four years after the tsunami does not seem to be a sufficient time for the long-term assessment of sustainability issues.

- **To investigate and assess the annual indoor thermal environmental performance of some representatives of post-tsunami houses:**

  The assessment is based on the three main house types commonly designed by the house donors, namely heavyweight house, semi-permanent house and lightweight house. The lightweight house is characterized by walls constructed of GRC board, and calsiboard (5mm-10mm thick). The semi-permanent house is constructed from plastered brick wall (150mm thick, 1m high above the floor) and wood plank (10mm thick, 2m high above the one meter brick wall), while the wall of the heavyweight house is constructed of clay brick and concrete brick with a thickness of 150 mm.

  Responding to these house constructions, the findings show that in general there is no significant difference in average inside temperature among the three types of those houses (heavy-, lightweight and semi-permanent). The mean inside temperature of all of these types is $30^0$C. However, the heavyweight house tends to have the slightly lower peak inside air temperature during the day and conversely higher than the outside air temperature when the sun goes down. In contrast, lightweight houses have an extremely high inside air temperature which is up by $5^0$C higher than the outside air temperature. Semi-permanent houses also tend to have higher inside air temperature; however, the value is slightly lower compared with the value in the lightweight house. The two house types (lightweight and semi-permanent) have lower inside air temperature than the value in heavyweight house when the sun is down.

  Another longer indoor thermal assessment was carried out on some unaffected existing houses and traditional Acehnese house for comparison. Except with the traditional Acehnese house, the study shows that there is no significant difference of inside air temperature between the post-tsunami houses and those unaffected by the tsunami (based on the house types, i.e heavyweight, semi-permanent and lightweight house). The inside air temperature values stand higher than the neutral temperature applicable in Indonesia. This confirms that the post-tsunami housing was built similarly to currently the currently typical houses in Aceh. While the traditional

Acehnese house was shown to have lower inside air temperature than the outside air temperature. It also shows that the mean inside temperature in the traditional Acehnese house is close to the comfort temperature proposed by Nicol and even meets the higher range of comfort temperature proposed by Karyono, which may be more applicable, since his work was carried out in Indonesia.

In terms of the indoor thermal sensations, the household qualifies the house based on the ASHRAE scale, namely -3, -2, -1, 0, 1, 2, 3 representing cold, cool, slightly cool, neutral, slightly warm, warm and hot respectively. The thermal sensation was rated during morning, afternoon and evening throughout the year. The heavyweight house type was voted as the most thermally comfortable one, with the scale of 1.26 (slightly warm) and followed afterwards by semi-permanent house (1.84) and the lightweight house (2.0; some even reaching up to 2.83). Apart from the thermal condition of those houses, these votes are also believed to be highly related to the house condition. It was found during the observation that the heavyweight houses donated by Turkish and Saudi Arabia which have beautiful performance have a better performance compared with other types; at the same time, this type is voted 0.33 (nearly neutral) on the thermal sensation scale by the households which is most thermally comfortable. While houses donated by IOM referring to lightweight house was voted as 2.84 (hot). Apart from such high inside air temperature during the day, this house also looks untidy in term of house design.

- **To provide some recommendations for good house design for the tsunami disaster victims which considers the local climate:**

  The proposed building recommendations are carried out from the conditions that mostly occurred when the houses were occupied (based on the questionnaire). The results show that the post-tsunami housing is built conventionally.

  - Due to the lack of integration between housing construction and house maintenance, especially for supporting the occupation stage such as power and water supply and treating waste, etc, this study recommends building housing to consider and prioritize local people's preferences by initially understanding sustainable house design. Housing should also be built from sustainable material meaning renewable, locally produced and containing no harmful materials. In this study bamboo is proposed to be used in any future post disaster reconstructions considering its rapid growth that can accommodate the future need of woods.

- Indoor thermal comfort should be of some concern as well. In this study, the guidelines to provide low inside air temperatures in a tropical climate were studied through the use of TAS building simulation software and the common building recommendations in tropic from several studies.

- The use of solar-powered lights are proposed since the electricity in Aceh is still a problem caused either by limited provision to the houses or limited power generating the electricity itself, causing light to be frequently cut. Therefore, in Aceh or any tropical areas where sunlight is quite abundant, solar-powered lights may be the best option to light post-disaster houses for any future disaster.

- As reviewed in the literature review, vegetation provision, both solid and liquid waste treatment, clean water provision and power supply to support the housing-life also need to be considered. These facilities should be integrated in the housing environment.

- Access to local public facilities contributes to the sustainability of the housing. This is considered by providing the nearest facilities in walking distance. If walking distance-public facilities are not accessible, direct the public transport to the nearest area.

The building recommendations are not only designed to be applicable in post-disaster areas specified in Aceh climate, but also in any housing developments in Aceh or similar areas.

- **To propose alternative house designs applying the building design guidelines recommended in this study responding to thermal building design in the tropics:**

  The proposed house models are designed in a simple layout accommodating the essential rooms, namely a living room, two bedrooms, a kitchen and a toilet. By utilising TAS building simulation software and applying the weather data of year 2009, the models were simulated to present the predicted annual inside air temperature. The house models use proposed materials such as bamboo and some other building materials commonly applied in Aceh, and they apply the house design variables that are presented in chapter 8. The models can provide a lower inside air temperature than the value in post-tsunami houses. The heavy- and lightweight house models can be improved to have lower peak inside air temperature by 2.1$^{0}$C and

3.6$^0$C respectively. The proposed house models with the estimated building price are not only applicable in post-disaster reconstruction but also in any housing developments in Aceh or any similar areas.

## 10.3 Recommendation

This study attempted to assess sustainability and thermal comfort in the post-reconstruction developments in Banda Aceh. While the speed with which new houses were erected following the Tsunami was impressive, the rapidity of the building process meant that sustainability was not addressed sufficiently in areas such as water and waste treatment, building materials, and some aspects of house design, as detailed earlier in chapter 5. The inclusion of sustainability must be integrated into the whole building process right from the beginning, to consider items ranging from site issues, through to occupancy and thermal comfort. In a disaster situations such as this the provision of immediate shelter is one of the main priorities, but further research on the lines indicated below point the way to a more sustainable way of approaching post-disaster construction.

- The environmental assessment on post-tsunami housing studied in this research is quite broad. In order to get a deeper view of this study, the more specific studies based on each assessed parameter should be carried out qualitatively apart from the quantitative method. The qualitative research is an interesting method to conduct this study, since it can find the things that are not initially expected. However, such study may take a longer period to carry out.
- The study of thermal comfort carried out in this study uses the thermal sensation rated during morning, afternoon and evening throughout the year, which is not simultaneously rated with the measurement. By using this approach, the neutral temperature cannot be obtained. Therefore to find the neutral temperature which is more applicable to Aceh climate in post-disaster case, a further and deeper study of thermal comfort with post-tsunami housing needs to be conducted by interview asking house occupants about the thermal sensation simultaneously with a mechanical measurement as undertaken by many researchers on the relevant study.
- In order to get the exact amount of energy used by the householders in kwh unit, further research on the relevant study is recommended to carry out the detail assessment by listing the appliances (e.g. TV, PC, radio, etc.) in each measured

house as well as getting the monthly bill of the householders and recording the habitual householders in switching on the equipments.

- The building simulation conducted in this study did not simulate the surfaces (i.e. grass, gravel, paving block, soil, etc.) around the simulated model since TAS does not provide such features. TAS also cannot show the significance on reducing the inside air temperature of the use of a white roof unlike other studies mostly did. Therefore apart from using a more specific computer modelling study on house design in the tropics, any future studies should also undertake field measurements that can give more significant and reliable information for dealing with building in the tropics.
- The study found that more than 50% of householders are satisfied with their houses. This satisfaction does not seem to relate to the onsite measurements, where some issues under the criteria such as thermal comfort, water supply and energy assessment, cannot be assessed more precisely due to some technical problems faced by the occupants. Many people are simply grateful that they have a house as permanent shelter and are not concerned with long-term sustainability issues. Hence, four years after the tsunami does not seem to be a sufficient time for the long-term assessment of sustainability issues. More studies need to be carried out in the next few years to understand how people deal with donated houses and how living environments will affect them.

# APPENDIX A – QUESTIONNAIRE

## SURVEY OF ENVIRONMENTAL PERFORMANCE ASSESSMENT OF TSUNAMI DONATED HOUSES IN BANDA ACEH

*Dear sir/ madam,*

*This survey is conducted as part of the doctorate research of staff of Architectural department of Syiah Kuala University which involves some Syiah Kuala University students in carrying out the interview process. It aims to assess the general environmental performance of tsunami donated houses with respect to thermal comfort, lighting, ventilation, air quality and some other supporting environmental issues. We would therefore like to ask you some questions related to that. We would like to emphasise that your responses are extremely useful to us and would greatly appreciate your answering these questions. Be assured that your responses will be completely anonymous and will only be used for the above purpose.*

**Ref. No:**

Name of interviewer………:……………………………………………………………………………………

Location of survey (sub district/ village/ street)………………………………………………………………

House provider

Date/ time…………………………………………………………………………………………………:

Name of interviewee…………………………………………………………………………………(optional)

Estimated date of when this house was built:……………………………………………………………………

Estimated price of this house:…………………………………………………………………………………

**A House Description**

**1** How do you describe your house?

a Raised floor house
b Single storey house (Bungalow)
c two-storey house (duplex)
d Detached house
e other, specify: ……………………………………

**2** How large is your house built by the house donator?

a <36m sq
b 36-45m sq
c 46-60m sq
d >60m sq

**3** How large was your house before being attacked by tsunami?

a <36m sq
b 36-45m sq
c 46-60m sq
d >60m sq

**4** Indicate number of the following rooms built by the house donator in your house

| | |
|---|---|
| Living room | |
| bed room | |
| kitchen | |

| | | |
|---|---|---|
| toilet/ shower/ bath room | | |
| Dining room | | |
| other, specify: | | |
| | | |
| | | |

**5** Indicate number of additional rooms you built

| | |
|---|---|
| Living room | |
| bed room | |
| kitchen | |

| | | |
|---|---|---|
| toilet/ shower/ bath room | | |
| Dining room | | |
| other, specify: | | |
| | | |
| | | |

**6** House construction and design was based on:

a own design
b Offered design by house donator which was selected by community
c Offered design by house donator which was selected by each beneficiary (householder)
d Others, specify:

**7** How many people live in your house?……………………………………………………………………

**8** Did you live here before?

a yes
b no

**9** If no, why do you live here now?……………………………………………………………………………

**B House materials**

**1** Roofs

a Slooping tiled roof
b Slooping aluminium roof
c Flat concrete roof
d Slooping zinc roof
e Sago leaf
f other, specify: ……………………………………
……………………………………

**1.1** Finishing:

a Painted , please specify in what colour:
b Not painted (left as its original material)
c Others:……………………………………………

**2** Wall

**2.1** External walls

a bricks + cement plaster
b concrete brick + cement plaster
c gypsum
d calsiboard
e bricks+cement palster and wood (plank)
f wood plank
g plywood
h other, specify: ……………………………………
……………………………………

**2.1.a Finishing:**

a Painted , please specify in what colour:
b Not painted (left as its original material)
c Others:.............................................

**2.2 Internal walls**

| | | | |
|---|---|---|---|
| a | bricks + cement plaster | f | wood plank |
| b | concrete brick + cement plaster | g | plywood |
| c | gypsum | h | other, specify: |
| d | calsiboard | | ............................................ |
| e | bricks+cement palster and wood (plank) | | ............................................ |

**2.2.a Finishing:**

a Painted , please specify in what colour:
b Not painted (left as its original material)
c Others:.............................................

**3 Floors**

| | | | |
|---|---|---|---|
| a | concrete base+ceramic tile | e | Laminated floor |
| b | concrete tile | f | other, specify |
| c | wood | | ............................................ |
| d | concrete + cement plaster | | ............................................ |

**4 Height of floor from the ground**

| | | | |
|---|---|---|---|
| a | <50 cm | c | >100cm |
| b | 50-100cm | | |

**5 Openings (Windows/ Doors)**

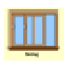
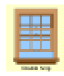
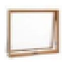
| Room | Description | Windows | Doors |
|---|---|---|---|
| Main room | material* | | |
| | thickness of material | | |
| | Type** | | |
| | orientation*** | | |
| | dimension | | |
| | width | | |
| | height | | |
| | level | | |

Note:

***Material:**

| | | | |
|---|---|---|---|
| a | single glass with wood frame | e | single glass with aluminium frame |
| b | double glass with wood frame | f | double glass with aluminium frame |
| c | wood | g | Aluminium |
| d | plastic | h | other, specify: |

****Type: a window type (tick any window types in the box)**

☐ casement 
☐ Louver 
☐ Sliding 
☐ Double/single hung 
☐ Awning 
☐ fixed
☐ others, specify:

****Type: b window type (tick any window types in the box)**

☐ folding door
☐ casement door
☐ sliding door
☐ others, specify:

*****Orientation:**

| | | | |
|---|---|---|---|
| a | south | e | south-east |
| b | north | f | north-east |
| c | west | g | south-west |
| d | east | h | north-west |

**6 Ceiling**

| | | | |
|---|---|---|---|
| a | Gypsum ceiling boards | d | wood panel ceiling |
| b | Asbestos ceiling boards | e | reinforced concrete ceiling |
| c | Calsiboard ceiling boards | f | other, specify: |
| | | | ............................................ |

**6.1 Finishing:**

a Painted , please specify in what colour:
b Not painted (left as its original material)
c Others:.............................................

**7 Column**

| | | | |
|---|---|---|---|
| a | Wood, specify what kind of wood: | c | Steel |
| b | Reinforced concrete | d | Brick/ Concrete brick |

**EMBODIED ENERGY** ……………………………………………

1 Do you know where all these materials used in your house are from?

| Materials | Yes, specify: *(e.g imported from medan, etc)* | No |
|---|---|---|
| Brick | | |
| Sand | | |
| Wood | | |
| Ply wood | | |
| Zinc sheet | | |
| Roof tile | | |
| Floor tile | | |
| Cement | | |
| Stone | | |
| Glass | | |
| Soil | | |
| aluminium | | |
| Asbestos | | |
| Steel | | |
| Others: | | |
| | | |
| | | |

2 Do you know where the labour were coming from?

## C Thermal Comfort

1 Personal Physical description

| Gender | age | weight (kg) | Height(cm) |
|---|---|---|---|
| | | | |

2 Clothing

please describe clothings you are wearing by just ticking in the box

| Garment | location: Living room Morning / Afternoon / evening | Bedroom Morning / Afternoon / evening | Kitchen Morning / Afternoon / evening |
|---|---|---|---|
| underwear | / / | / / | / / |
| Footwear | / / | / / | / / |
| Shirts / Blouses | / / | / / | / / |
| Trousers / coverals | / / | / / | / / |
| Suit jackets / vest | / / | / / | / / |
| Sweaters | / / | / / | / / |
| Longdress | / / | / / | / / |
| Sarung | / / | / / | / / |
| Skirt | / / | / / | / / |
| Others, specify: | / / | / / | / / |
| | / / | / / | / / |
| | / / | / / | / / |

3 Activity level

| Activities | Location: Living room Morning / Afternoon / evening | Bedroom Morning / Afternoon / evening | Kitchen Morning / Afternoon / evening |
|---|---|---|---|
| reclining | / / | / / | / / |
| sitted, relaxed | / / | / / | / / |
| standing with light activity | / / | / / | / / |
| standing with medium activity | / / | / / | / / |
| Others, specify: | / / | / / | / / |

4 Temperature in room

how do you feel about the inside temperature

| Time | Cold | Cool | Slightly cool | Neutral | Slightly warm | warm | hot |
|---|---|---|---|---|---|---|---|
| Morning | | | | | | | |
| Afternoon | | | | | | | |
| Evening | | | | | | | |

5 What normally do you feel the inside temperature during these months

| Season | Cold | Cool | Slightly cool | Neutral | Slightly warm | warm | hot |
|---|---|---|---|---|---|---|---|
| Dry season | | | | | | | |
| Rainy season | | | | | | | |

6 Would you like to have you internal temperature as these followings?

| Time | Cooler | No change | Warmer |
|---|---|---|---|
| Morning | | | |
| Afternoon | | | |
| Evening | | | |

7 Once you feel uncomfortable in the room what do you do to provide comfort?

(give the score from 1-7, where 1 is the most common)

| | | | |
|---|---|---|---|
| Open windows | | turn on electric fans | |
| Open doors | | Use air conditionairs | |
| use hand fans | | Use heaters | |
| take off layer of clothing | | other, specify:…………………………………… | |

**8 Air movement in room**

**8.1** How do you feel about the rate of air movement in the room (average during the day)?

a Very light	d moderate
b Light	e strong
c gentle	f others

**8.2** How do you feel about the quality of the air movement?

a smelly	c fresh
b just alright	d other, specify:…………………………………

**8.3** once it is smelly, where do you believe to be the source of the smell?

(give the score from 1-,4 where 1 is the most believed to be source of the smell)

from outside, specify:……………………………………………………………………………
from toilet
from kitchen
Other, specify………………………………………………………………………………………

**8.4** What kind of cooking apparatus is provided?

a cooker with gas cylinder	d Electric cooker
b cooker with kerosene	e others, specify
c Traditional cooker with Fire wood

**8.5** what type of cooking extract do you have?

a flue	c None
b open window	d others, specify

**D Lighting**

**1** How do you feel about the day light provision in overal of your house?

a gloomy
b good but supplementary artificial lighting is needed
c strongly day lit

**2** Are you satisfied with that?

a yes	b no

**3** What kind of lighting do you use at home?(specify number of hours you use the light per day)

| Type of lighting | Rooms: Living room (hours) | Bedroom (hours) | Kitchen (hours) | Toilet (hours) |
|---|---|---|---|---|
| Electric lighting (incandescent) | | | | |
| Electric lighting (fluorescent) | | | | |
| Gas lamp | | | | |
| Rechargeable lamp | | | | |
| kerosene lantern | | | | |
| lighting with battery power | | | | |
| photovoltaic light | | | | |
| Others, specify | | | | |

**E General Acoustic performance**

**1** what do you think about the general acoustic performance in your house?

a Very quite	c slightly noisy	e too noisy
b quite	d noisy

**2** Once you feel it is noisy or too noisy, where do you believe to be the noise source?

(give the score from 1-2 where 1 is the most believed to be source of the noise)

from inside, specify:……………………………………………………………………………
from outside, specify:…………………………………………………………………………

**F Enviromental/ surrounding assessment**

**1** Type of soil

a Sandy	c Clay	e Others, specify:
b Silty	d Chalky

**2** Is your area vulnerable to flooding?

a yes	b No

**3** If yes, how often does it happen in a year?

a 1	c >3
b 2

**4** How far is your house from sea/ river?

a < 1 km	c > 2 km
b 1-2km

**5** Are there any trees around your house? (if yes. Please mention its type!)

a yes, specify…………………………	b no
……………………………………………
……………………………………………

**6** what kind of surface does surround your house?

a paving block	c Ground
b Grass	d others, specify:

| G | Water and waste treatments | | | | | |
|---|---|---|---|---|---|---|
| 7 | is your house completed with drainage? | | | | | |
| | a | yes | | b | no | |
| | If, any problems, specify:……………………………………………………………………… | | | | | |
| 8 | is your house completed with septic tank? | | | | | |
| | a | yes | | b | no | |
| 8.1 | If, yes what type of septik tank do you have? | | | | | |
| | a | Plastic tank | c | Brick well | e | Others |
| | b | Soil digging | d | Concrete wall | | |
| | If, any problems, specify:……………………………………………………………………… | | | | | |
| 9 | where do you get your daily water needs from? | | | | | |
| | a | local shallow well | | c | centrally distributed water | |
| | b | local deep well | | d | other, specify: | |
| | | | | | ……………………………… | |
| 9.1 | How is that water's quality? | | | | | |
| | a | Good and can be directly consumed | | c | Smelly and coloured | |
| | b | Good but still need to be cooked prior the consumption | | d | Others, specify: | |
| 10 | Do you have your grey water production recycled | | | | | |
| | a | yes, specify how: | | b | No | |
| 11 | Do you harvest rain? | a | yes | b | No | |
| 11.1 | If yes, what do you use it for? | | | | | |
| | a | Watering plants | | c | Cooking | |
| | b | Washing car/ vehicle | | d | Others, specify: | |
| 12 | do you have any regular garbage/ sewage collections in your neighbourhood? | | | | | |
| | a | yes | | b | no | |
| 12.1 | If yes, who organise the collection? | | | | | |
| | a | Government | | c | Local community | |
| | b | private company | | d | others, specify: | |
| 13 | If no, how do you organise those sewages? | | | | | |
| | (give the score from 1-5 where 1 is the highest frecuency you do it) | | | | | |
| | burn | | | through them away any where | | |
| | compost | | | other, specifiy………………… | | |
| | burried | | | ……………………………………… | | |

| H | Access to local facilities (between 500 m- 1 km from your neighbourhood) | | | |
|---|---|---|---|---|
| 14 | Are there any health centers around your neighbourhood? | | | |
| | a | yes | b | no |
| | If, any problems, specify:……………………………………………………………………… | | | |
| 15 | Are there any schools around your neighbourhood? | | | |
| | a | yes | b | no |
| | If, any problems, specify:……………………………………………………………………… | | | |
| 16 | Are there any prayer building around your neighbourhood? | | | |
| | a | yes | b | no |
| | If, any problems, specify:……………………………………………………………………… | | | |
| 17 | Are there any markets around your neighbourhood? | | | |
| | a | yes | b | no |
| | If, any problems, specify:……………………………………………………………………… | | | |
| 18 | Are there any public toilets around your neighbourhood? | | | |
| | a | yes | b | no |
| | If, any problems, specify:……………………………………………………………………… | | | |
| 19 | Are there any public space, such as open space, playing ground etc, around your neighbourhood? | | | |
| | a | yes | b | no |
| | If, any problems, specify:……………………………………………………………………… | | | |
| 20 | can you get the public transport from your neighbourhood easily? | | | |
| | a | yes | b | no |
| | If, any problems, specify:……………………………………………………………………… | | | |

**I Health consideration in houses design**

**21** Once you are inside your house, have you ever been effected by these following illness?

| illness | yes/ no | duration | |
|---|---|---|---|
| | | often | sometime |
| headache | | | |
| eye irritation | | | |
| nose irritation | | | |
| throat irritation | | | |
| dry cough | | | |
| dry skin | | | |
| itchy skin | | | |
| dizziness | | | |
| Difficulty in concentrating | | | |
| Fatigue | | | |
| Sensitivity to odors | | | |
| asthma | | | |
| depression | | | |
| others, specify:………………… | | | |
| ……………………………………… | | | |

| J | Energy assessment | | |
|---|---|---|---|
| 1 | Do you use these following fuels/ powers to generate your daily appliances? (please tick in the box below) | | |

| | | |
|---|---|---|
| Electric | | If yes, please go to question number 2 |
| Gas | | If yes, please go to question number 3 |
| Kerosene | | If yes, please go to question number 4 |
| Others | | If yes, please go to question number 5 |

**2** How many kwh does your electric run every month?.......................................................................

**2.1** How much do you pay the electric bill monthly?...........................................................................

| | | | |
|---|---|---|---|
| a | <Rp.100.000,- | c | >Rp.200.000,- |
| b | Rp.100.00,- Rp. 200.000,- | | |

**3** How long do you use per one gas cylinder?.......................................................................................

| | | | |
|---|---|---|---|
| a | <3 weeks | c | >5weeks |
| b | 3-5 weeks | | |

**3.1** How much do you pay per gas cylinder?

| | | | |
|---|---|---|---|
| a | <Rp.100.000,- | c | >Rp.200.000,- |
| b | Rp.100.00,- Rp. 200.000,- | | |

**4** How much kerosene do you use permonth? (Liter)

| | | | |
|---|---|---|---|
| a | <10 liters | c | >20 liters |
| b | 10-20 iters | | |

**4.1** How much is kerosene per liter?

| | | | |
|---|---|---|---|
| a | <Rp.5.000,- | c | >Rp.30.000,- |
| b | Rp.10.00, Rp. 30.000, | | |

**5** How much do you use this fuel per month?

**5.1** How much does it cost?

**6** How many L/m does your water meter run every month?

**6.1** How much do you pay the water bill monthly?

| | | | |
|---|---|---|---|
| a | <Rp.100.000, | c | >Rp.200.000, |
| b | Rp.100.00,- Rp. 200.000,- | | |

| K | General perception on this house |
|---|---|
| | Are you satisfied with the overall performance of this house? (including house design, indoor comfort, construction, material etc) |
| | Yes, because: |
| | No, because: |

*This is the end of this questionnaire, we do really appreciate and thank you for answering all questions properly and all good cooperation conducted during the survey process.*

# APPENDIX B – INDOOR THERMAL PERFORMANCE OF 20 POST TSUNAMI HOUSES MEASURED OVER 2 DAYS (FIELD TRIP DATA)

| House types | Measuring date | | Rhi | Tai | Tao | Rho | Avo |
|---|---|---|---|---|---|---|---|
| BRR | A 20-21 May 2009 | avg | 66.4 | 29.7 | 28.1 | 73.0 | 2.0 |
| | | max | 75.5 | 32.3 | 33.4 | 95.0 | 4.6 |
| | | min | 56.0 | 27.9 | 23.8 | 47.0 | 0.0 |
| | B 29-30 June 2009 | avg | 58.4 | 31.5 | 28.8 | 70.2 | 1.7 |
| | | max | 67.8 | 34.4 | 33.2 | 97.0 | 3.6 |
| | | min | 45.0 | 28.1 | 23.6 | 45.0 | 0.0 |
| Uplink | a 22-23 May 2009 | avg | 66.7 | 30.7 | 28.5 | 75.4 | 1.8 |
| | | max | 76.6 | 36.0 | 34.2 | 93.0 | 3.6 |
| | | min | 48.7 | 25.5 | 23.4 | 48.0 | 0.0 |
| | B 24-26 May 2009 | avg | 67.1 | 30.2 | 28.4 | 75.4 | 1.8 |
| | | max | 77.5 | 34.5 | 34.4 | 97.0 | 5.1 |
| | | min | 54.3 | 27.4 | 24.2 | 47.0 | 0.0 |
| Turkish Red Crescent | A 27-28 May 2009 | avg | 67.5 | 30.6 | 27.6 | 80.4 | 1.6 |
| | | max | 77.0 | 33.0 | 34.8 | 95.0 | 7.2 |
| | | min | 60.3 | 28.6 | 24.0 | 48.0 | 0.0 |
| | b 29-30 May 2009 | avg | 66.5 | 29.7 | 27.7 | 76.6 | 2.1 |
| | | max | 80.2 | 33.0 | 34.2 | 93.0 | 5.1 |
| | | min | 51.4 | 27.0 | 24.0 | 43.0 | 0.0 |
| YBI | A 1-2 June 2009 | avg | 67.5 | 30.7 | 29.4 | 65.6 | 2.6 |
| | | max | 80.9 | 33.8 | 33.4 | 92.0 | 5.1 |
| | | min | 55.9 | 28.1 | 24.4 | 49.0 | 0.0 |
| | B 3-4 June 2009 | avg | 62.3 | 30.6 | 30.2 | 58.1 | 3.4 |
| | | max | 68.3 | 33.4 | 34.4 | 95.0 | 7.7 |
| | | min | 55.7 | 29.1 | 23.6 | 43.0 | 0.0 |
| Saudi Arabia | a 5-6 June 2009 | avg | 54.0 | 32.0 | 28.9 | 65.0 | 2.0 |
| | | max | 61.5 | 33.8 | 35.4 | 91.0 | 6.2 |
| | | min | 43.6 | 30.6 | 21.8 | 37.0 | 0.0 |
| | b 8-9 June 2009 | avg | 52.0 | 31.9 | 28.3 | 61.3 | 2.1 |
| | | max | 56.0 | 34.3 | 34.8 | 91.0 | 5.1 |
| | | min | 45.7 | 29.2 | 21.6 | 34.0 | 0.0 |
| Muslim Aid | A 10-11 June 2009 | avg | 60.3 | 30.9 | 28.5 | 73.1 | 1.8 |
| | | max | 75.2 | 35.8 | 34.4 | 95.0 | 5.1 |
| | | min | 43.9 | 25.0 | 22.8 | 43.0 | 0.0 |
| | B 15-16 June 2009 | avg | 61.7 | 29.8 | 29.4 | 55.9 | 2.9 |
| | | max | 67.7 | 32.1 | 33.6 | 88.0 | 7.2 |
| | | min | 52.7 | 27.9 | 24.5 | 34.0 | 0.0 |
| World Vision | A 12-13 June 2009 | avg | 65.9 | 31.2 | 28.6 | 71.0 | 2.1 |
| | | max | 71.2 | 32.8 | 33.8 | 97.0 | 5.7 |
| | | min | 62.3 | 29.6 | 23.6 | 50.0 | 0.0 |
| | b 19-20 June 2009 | avg | 64.2 | 31.3 | 28.6 | 71.7 | 2.1 |
| | | max | 72.7 | 33.7 | 33.6 | 93.0 | 5.7 |
| | | min | 54.7 | 28.6 | 23.6 | 50.0 | 0.0 |
| IOM | a 17-18 June 2009 | avg | 61.8 | 30.9 | 29.2 | 66.4 | 2.2 |
| | | max | 77.8 | 36.3 | 35.0 | 95.0 | 5.1 |
| | | min | 43.7 | 26.4 | 23.8 | 41.0 | 0.0 |
| | b | avg | 62.2 | 30.8 | 28.5 | 66.9 | 2.3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 22-23 June 2009 | max | 74.5 | 36.0 | 34.0 | 88.0 | 6.7 |
| | | min | 49.1 | 26.8 | 23.8 | 43.0 | 0.0 |
| UN Habitat | A<br>24-25 June 2009 | avg | 62.6 | 30.5 | 28.5 | 69.3 | 2.0 |
| | | max | 73.8 | 32.6 | 35.2 | 95.0 | 4.1 |
| | | min | 48.1 | 28.4 | 23.0 | 41.0 | 0.0 |
| ADB | B<br>26-27 June 2009 | avg | 70.7 | 28.6 | 26.7 | 77.4 | 1.8 |
| | | max | 84.1 | 32.8 | 33.4 | 97.0 | 7.2 |
| | | min | 52.6 | 26.5 | 22.9 | 43.0 | 0.0 |
| Budha Tzu Chi | A<br>1-2 July 2009 | avg | 60.3 | 31.6 | 27.7 | 74.6 | 1.5 |
| | | max | 74.7 | 37.3 | 34.8 | 95.0 | 4.1 |
| | | min | 42.7 | 27.0 | 23.0 | 42.0 | 0.0 |
| | B<br>3-14 July 2009 | avg | 64.4 | 31.0 | 28.5 | 69.7 | 2.1 |
| | | max | 79.0 | 37.9 | 34.9 | 97.0 | 7.7 |
| | | min | 44.9 | 26.8 | 23.2 | 42.0 | 0.0 |

| House types | | Month | Hour | Outside Air velocity | Air velocity | | Inside Surface Temperature | | | | | | | | | | Tao |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Living Room | | | | | Bed Room | | | | | |
| | | | | | Living Room | Bed Room | Wall | Ceiling | Floor | Glass | Door | Wall | Ceiling | Floor | Glass | Door | |
| B1 | a | 20-May-09 | 10.00-11.00 | 1.05 | 0.05 | 0.04 | 30.3 | 33.3 | 30.9 | 32.3 | 32.3 | 30.2 | 32.8 | 30.6 | 32.0 | 32.2 | 29.4 |
| | | | 15.00-16.00 | 3.10 | 0.06 | 0.04 | 32.7 | 33.0 | 31.4 | 33.3 | 33.1 | 31.3 | 33.7 | 30.6 | 31.8 | 31.6 | 31.3 |
| | | 21-May-09 | 10.00-11.00 | 0.75 | 0.03 | 0.03 | 30.3 | 39.0 | 31.2 | 33.3 | 32.2 | 31.6 | 34.5 | 30.4 | 33.5 | 30.8 | 30.2 |
| | | | 15.00-16.00 | 3.60 | 0.19 | 0.03 | 32.5 | 38.2 | 32.2 | 35.7 | 34.6 | 32.3 | 35.9 | 31.3 | 33.0 | 32.8 | 33.1 |
| | b | 29-Jun-09 | 10.00-11.00 | 0.00 | 0.24 | 0.14 | 30.0 | 40.9 | 32.3 | 35.7 | 33.1 | 29.6 | 40.4 | 31.4 | 34.9 | 31.9 | 30.8 |
| | | | 15.00-16.00 | 2.60 | 0.15 | 0.12 | 33.9 | 37.2 | 33.0 | 35.5 | 34.5 | 33.9 | 36.9 | 32.5 | 35.6 | 34.1 | 32.6 |
| | | 30-Jun-09 | 10.00-11.00 | 1.80 | 0.07 | 0.13 | 30.1 | 38.9 | 32.5 | 34.3 | 32.7 | 30.0 | 39.4 | 31.8 | 33.5 | 31.9 | 30.4 |
| | | | 15.00-16.00 | 3.10 | 0.11 | 0.09 | 33.2 | 39.8 | 33.1 | 34.8 | 34.5 | 33.4 | 40.5 | 32.6 | 35.8 | 33.7 | 32.0 |
| U2 | a | 22-May-09 | 10.00-11.00 | 0.75 | 0.12 | 0.11 | 33.2 | 35.9 | 34.4 | 36.3 | 35.1 | 34.3 | 37.4 | 33.3 | 35.6 | 34.4 | 31.3 |
| | | | 15.00-16.00 | 2.85 | 0.12 | 0.11 | 35.4 | 40.0 | 35.6 | 35.0 | 35.3 | 41.3 | 42.0 | 37.3 | 35.9 | 35.5 | 33.5 |
| | | 23-May-09 | 10.00-11.00 | 0.75 | 0.11 | 0.14 | 32.7 | 37.0 | 33.3 | 34.1 | 34.0 | 33.4 | 36.6 | 32.6 | 33.3 | 32.1 | 28.8 |
| | | | 15.00-16.00 | 2.85 | 0.14 | 0.07 | 34.6 | 37.8 | 34.9 | 35.6 | 35.3 | 40.4 | 40.2 | 36.6 | 36.3 | 34.9 | 32.3 |
| | b | 24-May-09 | 10.00-11.00 | 1.05 | 0.08 | 0.08 | 33.3 | 37.3 | 31.1 | 35.6 | 30.9 | 29.4 | 30.0 | 28.7 | 32.3 | 30.2 | 29.6 |
| | | | 15.00-16.00 | 3.35 | 0.08 | 0.05 | 34.0 | 34.5 | 33.1 | 32.2 | 34.0 | 32.0 | 31.9 | 29.5 | 31.5 | 31.7 | 33.3 |
| | | 26-May-09 | 10.00-11.00 | 2.55 | 0.10 | 0.13 | 33.3 | 35.7 | 31.3 | 35.0 | 30.5 | 29.8 | 30.4 | 28.9 | 32.8 | 30.3 | 33.2 |
| | | | 15.00-16.00 | 3.60 | 0.11 | 0.09 | 35.2 | 37.4 | 33.3 | 34.8 | 31.8 | 32.4 | 32.4 | 30.3 | 34.2 | 32.0 | 33.5 |
| T3 | a | 27-May-09 | 10.00-11.00 | 1.05 | 0.15 | 0.06 | 31.3 | 35.5 | 32.3 | 35.9 | 34.4 | 31.2 | 36.8 | 31.6 | 35.7 | 31.9 | 30.4 |
| | | | 15.00-16.00 | 3.85 | 0.43 | 0.08 | 32.8 | 35.8 | 32.6 | 35.8 | 35.1 | 33.1 | 36.6 | 32.4 | 35.1 | 33.8 | 32.4 |
| | | 28-May-09 | 10.00-11.00 | 1.80 | 0.12 | 0.08 | 29.7 | 32.0 | 30.8 | 32.3 | 30.6 | 30.4 | 32.3 | 30.6 | 32.8 | 29.9 | 27.3 |
| | | | 15.00-16.00 | 2.60 | 0.08 | 0.07 | 31.9 | 35.2 | 32.5 | 35.1 | 34.1 | 32.1 | 35.8 | 32.0 | 35.5 | 32.7 | 31.4 |
| | b | 29-May-09 | 10.00-11.00 | 1.50 | 0.38 | 0.09 | 29.9 | 32.6 | 31.0 | 34.3 | 32.4 | 30.7 | 34.8 | 31.1 | 36.1 | 30.9 | 30.0 |
| | | | 15.00-16.00 | 3.85 | 0.26 | 0.14 | 31.0 | 29.1 | 30.6 | 29.0 | 28.8 | 31.0 | 29.7 | 30.7 | 27.7 | 30.1 | 24.9 |
| | | 30-May-09 | 10.00-11.00 | 1.05 | 0.30 | 0.21 | 32.4 | 34.9 | 32.5 | 35.0 | 33.2 | 31.8 | 34.9 | 32.1 | 35.2 | 32.5 | 30.5 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 15.00-16.00 | 3.10 | 0.13 | 0.11 | 32.8 | 35.5 | 32.2 | 35.7 | 33.3 | 31.9 | 36.8 | 31.5 | 37.1 | 32.8 | 33.8 |
| Y4 | a | 01-Jun-09 | 10.00-11.00 | 1.80 | 0.22 | 0.09 | 32.1 | 34.8 | 29.9 | 34.4 | 32.3 | 35.4 | 35.9 | 30.4 | 38.0 | 32.4 | 30.7 |
| | | | 15.00-16.00 | 4.85 | 0.23 | 0.13 | 36.2 | 35.9 | 30.9 | 34.1 | 34.1 | 35.7 | 37.3 | 31.0 | 35.6 | 34.2 | 32.5 |
| | | 02-Jun-09 | 10.00-11.00 | 2.30 | 0.14 | 0.06 | 29.5 | 33.6 | 30.1 | 32.8 | 31.0 | 32.6 | 34.3 | 30.3 | 36.6 | 31.3 | 30.9 |
| | | | 15.00-16.00 | 3.35 | 0.14 | 0.12 | 35.0 | 35.3 | 31.0 | 34.2 | 33.7 | 34.4 | 35.9 | 31.2 | 34.9 | 33.6 | 32.4 |
| | b | 03-Jun-09 | 10.00-11.00 | 2.05 | 0.13 | 0.11 | 32.7 | 33.2 | 31.2 | 34.5 | 32.1 | 31.6 | 32.9 | 30.8 | 32.6 | 31.6 | 32.9 |
| | | | 15.00-16.00 | 4.85 | 0.25 | 0.12 | 32.6 | 33.6 | 31.5 | 33.8 | 32.7 | 32.4 | 34.0 | 30.9 | 32.7 | 32.4 | 33.9 |
| | | 04-Jun-09 | 10.00-11.00 | 4.65 | 0.24 | 0.07 | 32.7 | 33.6 | 31.2 | 34.9 | 32.6 | 31.5 | 33.9 | 30.6 | 32.8 | 31.6 | 32.1 |
| | | | 15.00-16.00 | 5.90 | 0.30 | 0.14 | 33.5 | 34.4 | 32.4 | 34.4 | 33.5 | 33.2 | 34.5 | 31.6 | 33.8 | 33.2 | 33.0 |
| UE5 | a | 05-Jun-09 | 10.00-11.00 | 4.60 | 0.26 | 0.15 | 31.4 | 33.9 | 31.5 | 34.8 | 32.6 | 31.3 | 34.4 | 31.5 | 36.6 | 31.4 | 32.6 |
| | | | 15.00-16.00 | 3.10 | 0.32 | 0.15 | 33.5 | 35.3 | 32.4 | 35.4 | 33.5 | 33.7 | 35.0 | 75.2 | 36.7 | 33.2 | 33.1 |
| | | 06-Jun-09 | 10.00-11.00 | 0.50 | 0.15 | 0.12 | 31.1 | 35.6 | 31.1 | 34.7 | 32.5 | 31.0 | 86.6 | 31.7 | 37.8 | 31.8 | 33.0 |
| | | | 15.00-16.00 | 2.85 | 0.21 | 0.17 | 33.1 | 36.4 | 32.4 | 35.8 | 33.5 | 34.0 | 36.3 | 32.0 | 37.1 | 33.3 | 34.7 |
| | b | 08-Jun-09 | 10.00-11.00 | 2.55 | 0.14 | 0.10 | 32.5 | 37.1 | 32.4 | 37.9 | 31.2 | 39.5 | 39.5 | 32.6 | 37.7 | 32.9 | 32.1 |
| | | | 15.00-16.00 | 4.10 | 0.19 | 0.24 | 35.0 | 37.9 | 33.2 | 38.8 | 34.1 | 37.1 | 37.1 | 32.8 | 39.1 | 34.5 | 34.0 |
| | | 09-Jun-09 | 10.00-11.00 | 1.00 | 0.32 | 0.15 | 30.8 | 37.9 | 32.4 | 36.7 | 33.6 | 31.4 | 40.2 | 32.6 | 38.8 | 32.1 | 31.2 |
| | | | 15.00-16.00 | 3.60 | 0.30 | 0.10 | 34.4 | 37.6 | 32.8 | 41.4 | 34.3 | 33.1 | 36.8 | 32.0 | 39.1 | 34.3 | 34.6 |
| M6 | a | 10-Jun-09 | 10.00-11.00 | 0.00 | 0.12 | 0.09 | 42.9 | 35.6 | 34.4 | 40.2 | 35.5 | 38.0 | 34.5 | 33.5 | 34.8 | 35.8 | 31.3 |
| | | | 15.00-16.00 | 3.60 | 0.12 | 0.09 | 36.5 | 36.0 | 35.2 | 36.7 | 36.3 | 40.8 | 36.6 | 37.2 | 37.1 | 38.0 | 34.1 |
| | | 11-Jun-09 | 10.00-11.00 | 0.75 | 0.15 | 0.07 | 44.5 | 35.8 | 34.2 | 42.7 | 35.8 | 37.3 | 35.2 | 33.5 | 34.2 | 36.6 | 30.1 |
| | | | 15.00-16.00 | 4.1 | 0.12 | 0.10 | 36.4 | 35.6 | 35.0 | 36.3 | 35.7 | 39.9 | 36.3 | 37.0 | 36.8 | 37.4 | 32.7 |
| | b | 15-Jun-09 | 10.00-11.00 | 3.35 | 0.17 | 0.12 | 31.3 | 31.2 | 31.1 | 31.8 | 31.0 | 31.3 | 31.5 | 31.0 | 31.3 | 30.7 | 30.9 |
| | | | 15.00-16.00 | 3.85 | 0.32 | 0.43 | 31.2 | 31.1 | 31.3 | 31.1 | 30.7 | 32.8 | 31.5 | 31.5 | 32.4 | 31.3 | 31.6 |
| | | 16-Jun-09 | 10.00-11.00 | 4.65 | 0.34 | 0.12 | 31.9 | 32.4 | 31.6 | 32.0 | 31.6 | 31.9 | 31.9 | 31.5 | 32.2 | 31.4 | 32.0 |
| | | | 15.00-16.00 | 5.15 | 0.28 | 0.16 | 32.8 | 32.7 | 32.3 | 32.5 | 32.2 | 36.0 | 33.4 | 33.2 | 34.9 | 32.6 | 32.8 |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W7 | a | 12-Jun-09 | 10.00-11.00 | 3.90 | 0.09 | 0.07 | 30.4 | 36.6 | 31.0 | 35.0 | 34.3 | 31.4 | 31.8 | 31.3 | 31.5 | 31.6 | 30.7 |
| | | | 15.00-16.00 | 3.85 | 0.12 | 0.13 | 33.4 | 30.6 | 31.5 | 34.3 | 34.0 | 32.1 | 32.2 | 31.4 | 32.2 | 32.3 | 32.3 |
| | | 13-Jun-09 | 10.00-11.00 | 2.55 | 0.09 | 0.17 | 30.7 | 36.5 | 31.4 | 35.1 | 30.6 | 32.5 | 32.7 | 32.0 | 32.1 | 32.5 | 31.0 |
| | | | 15.00-16.00 | 4.10 | 0.16 | 0.10 | 32.6 | 34.1 | 31.4 | 33.9 | 33.4 | 31.8 | 32.2 | 31.2 | 27.4 | 32.0 | 29.6 |
| | b | 19-Jun-09 | 10.00-11.00 | 1.25 | 0.20 | 0.12 | 33.6 | 52.1 | 32.9 | 37.3 | 33.9 | 31.6 | 32.2 | 31.6 | 32.5 | 32.2 | 31.9 |
| | | | 15.00-16.00 | 3.85 | 0.24 | 0.35 | 34.5 | 38.3 | 32.5 | 34.4 | 34.0 | 31.9 | 33.0 | 31.8 | 32.9 | 33.0 | 32.8 |
| | | 20-Jun-09 | 10.00-11.00 | 1.80 | 0.19 | 0.13 | 33.5 | 49.6 | 32.4 | 36.2 | 34.2 | 31.6 | 31.7 | 31.5 | 32.6 | 32.1 | 30.8 |
| | | | 15.00-16.00 | 4.35 | 0.27 | 0.16 | 34.7 | 38.7 | 32.3 | 35.5 | 34.8 | 32.0 | 33.4 | 31.9 | 35.3 | 34.3 | 32.8 |
| I8 | a | 17-Jun-09 | 10.00-11.00 | 3.10 | 0.29 | 0.14 | 35.6 | 44.9 | 33.4 | 35.0 | 35.8 | 38.6 | 46.3 | 32.4 | 36.9 | 36.3 | 33.3 |
| | | | 15.00-16.00 | 4.85 | 0.21 | 0.07 | 34.9 | 37.7 | 33.4 | 33.8 | 34.8 | 37.4 | 41.3 | 32.6 | 35.7 | 35.9 | 33.2 |
| | | 18-Jun-09 | 10.00-11.00 | 2.60 | 0.28 | 0.10 | 34.2 | 43.0 | 32.0 | 34.1 | 34.1 | 35.9 | 42.9 | 31.3 | 34.5 | 34.0 | 32.6 |
| | | | 15.00-16.00 | 3.85 | 0.25 | 0.09 | 38.4 | 42.3 | 35.1 | 35.7 | 37.1 | 44.2 | 52.4 | 33.8 | 40.6 | 38.7 | 34.5 |
| | b | 22-Jun-09 | 10.00-11.00 | 2.35 | 0.20 | 0.12 | 36.4 | 50.3 | 33.2 | 35.5 | 35.7 | 36.1 | 45.5 | 32.9 | 36.3 | 36.3 | 32.2 |
| | | | 15.00-16.00 | 4.60 | 0.32 | 0.19 | 36.0 | 44.4 | 34.0 | 34.8 | 36.2 | 39.1 | 45.0 | 33.8 | 36.4 | 36.4 | 33.3 |
| | | 23-Jun-09 | 10.00-11.00 | 1.05 | 0.27 | 0.11 | 35.3 | 40.3 | 33.0 | 33.9 | 35.2 | 35.2 | 39.2 | 33.0 | 34.3 | 35.2 | 31.6 |
| | | | 15.00-16.00 | 3.35 | 0.31 | 0.14 | 35.3 | 43.4 | 34.5 | 33.9 | 35.0 | 38.4 | 42.1 | 34.2 | 35.7 | 35.5 | 33.5 |
| UA9 | a | 24-Jun-09 | 10.00-11.00 | 2.05 | 0.16 | 0.17 | 29.3 | 30.3 | 30.1 | 31.2 | 30.8 | 29.7 | 32.3 | 30.6 | 33.1 | 30.9 | 30.1 |
| | | | 15.00-16.00 | 2.60 | 0.09 | 0.11 | 31.9 | 32.5 | 31.3 | 33.8 | 32.9 | 33.9 | 36.0 | 33.3 | 35.4 | 34.1 | 35.1 |
| | | 25-Jun-09 | 10.00-11.00 | 2.10 | 0.10 | 0.13 | 29.9 | 31.6 | 30.6 | 31.3 | 30.8 | 31.0 | 34.7 | 31.8 | 34.9 | 31.9 | 30.3 |
| | | | 15.00-16.00 | 3.60 | 0.08 | 0.13 | 32.0 | 32.5 | 31.2 | 32.7 | 32.6 | 34.7 | 36.6 | 34.0 | 35.4 | 34.6 | 32.4 |
| | b | 26-Jun-09 | 10.00-11.00 | 2.10 | 0.34 | 0.16 | 30.9 | 30.6 | 30.9 | 32.2 | 32.1 | 29.6 | 33.1 | 31.1 | 32.4 | 30.8 | 31.0 |
| | | | 15.00-16.00 | 5.40 | 0.49 | 0.30 | 35.9 | 34.1 | 33.6 | 38.9 | 38.4 | 34.6 | 36.1 | 34.4 | 35.1 | 33.6 | 33.3 |
| | | 27-Jun-09 | 10.00-11.00 | 1.25 | 0.48 | 0.17 | 29.3 | 29.2 | 30.2 | 29.7 | 30.6 | 28.0 | 29.1 | 29.0 | 28.1 | 28.4 | 29.6 |
| | | | 15.00-16.00 | 3.35 | 0.33 | 0.23 | 32.0 | 30.3 | 30.3 | 31.0 | 30.7 | 31.1 | 30.9 | 30.6 | 30.6 | 30.4 | 25.4 |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BT10 | a | 01-Jul-09 | 10.00-11.00 | 1.80 | 0.30 | 0.17 | 35.8 | 43.7 | 33.8 | 38.1 | 38.1 | 38.4 | 47.0 | 35.2 | 40.6 | 36.7 | 29.9 |
| | | | 15.00-16.00 | 2.42 | 0.15 | 0.08 | 36.5 | 39.3 | 35.2 | 35.7 | 36.5 | 38.0 | 42.6 | 36.0 | 36.9 | 37.2 | 30.6 |
| | | 02-Jul-09 | 10.00-11.00 | 1.31 | 0.23 | 0.06 | 34.6 | 43.3 | 33.5 | 37.1 | 37.1 | 37.9 | 47.3 | 34.3 | 39.1 | 35.2 | 30.1 |
| | | | 15.00-16.00 | 2.17 | 0.13 | 0.06 | 36.8 | 41.2 | 35.1 | 36.8 | 37.0 | 38.5 | 44.6 | 36.1 | 37.8 | 37.9 | 33.0 |
| | b | 03-Jul-09 | 10.00-11.00 | 1.80 | 0.18 | 0.09 | 31.8 | 36.4 | 31.5 | 32.1 | 31.9 | 32.9 | 40.6 | 32.0 | 33.7 | 32.9 | 31.2 |
| | | | 15.00-16.00 | 5.40 | 0.21 | 0.08 | 29.9 | 31.9 | 30.8 | 29.0 | 28.7 | 32.4 | 35.8 | 31.9 | 31.5 | 31.9 | 32.3 |
| | | 04-Jul-09 | 10.00-11.00 | 1.05 | 0.33 | 0.10 | 32.5 | 39.1 | 32.0 | 33.3 | 32.6 | 33.8 | 45.1 | 32.0 | 34.1 | 33.5 | 30.8 |
| | | | 15.00-16.00 | 3.35 | 0.23 | 0.06 | 32.9 | 36.9 | 32.2 | 33.4 | 33.3 | 33.8 | 40.4 | 32.7 | 34.3 | 33.5 | 32.6 |

# APPENDIX C – ESTIMATION OF WALL AND ROOF CONSTRUCTION PRICE USED IN THE PROPOSED HOUSE MODELS

The proposed house models simulated in this study use the proposed building materials including the common materials used in Aceh reconstruction such as brick, GRC board, plywood and the alternative material such as bamboo. The estimated prices of the wall and roof construction used in the proposed house models are simplified from the calculation of house designed by Zainal (2006). The simplification is obtained from the sum of the total price of wall divided by the total of wall surface area (327 m2)[1] and the roof price per m2. The price is estimated in per m2 to get it easily applicable in various size and design. The prices of the building materials per unit are obtained from Keputusan Gubernur Nanggroe Aceh Darussalam (2008), Daftar harga bangunan (2010), Enersia Conserva Suplindo (2011), and Bamboo Awet (2011)

## 1. 15cm bamboo wall + white painted zinc roof

| BAMBOO CONSTRUCTION | estimated number of supporting material | | price per unit (IDR) | total price (IDR) |
|---|---|---|---|---|
| bamboo (length:6m, diameter: 15cm) | 364 | unit | 40000 | 14560000 |
| bamboo tightener (ijuk) | 364 | unit | 20000 | 7280000 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 26172750 |
| | | | price of wall per m2 | 80038.99 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 116524.5~ **IDR 116,550.00** |

## 2. plastered brick +white painted zinc roof

| BRICK WORK | estimated number of supporting material | | price per unit (IDR) | total price (IDR) |
|---|---|---|---|---|
| brick | 17880 | units | 600 | 10728000 |
| cement | 378 | packs | 37000 | 13986000 |
| sand | 38.5 | m3 | 114600 | 4412100 |
| rock | 13.6 | m3 | 456700 | 6211120 |

[1] The wall surface area of house designed by ..where the price calculation is adopted to be used in this proposed house model

| | | | | |
|---|---|---|---|---|
| iron steel 12mm | 1470 | kg | 8050 | 11833500 |
| iron steel 9mm | 102 | kg | 8100 | 826200 |
| iron steel 6mm | 86 | kg | 8100 | 696600 |
| concrete wire | 39 | kg | 19600 | 764400 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 53790670 |
| | | | total price of wall per m2 | 164497.5 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 200983~ **IDR 201,000.00** |

## 3. Double GRC insulated with 5cm mineral wool board + white painted zinc roof

| DOUBLE GRC BOARDS INSULATED WITH 5 CM MINERAL WOOL BOARD | estimated number of supporting material | | price per unit (IDR) | total price (IDR) |
|---|---|---|---|---|
| GRC board 4mm | 273 | pieces | 46000 | 12558000 |
| mineral wool board (120X60X0.5cm) | 455 | pieces | 55000 | 25025000 |
| timber frame | 2.4 | unit | 4889600 | 11735040 |
| nail | 3.6 | kg | 15400 | 55440 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 53706230 |
| | | | total price of wall per m2 | 164239.2 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 200724.8~ **IDR 200,750.00** |

## 4. 15cm bamboo wall + white painted zinc roof insulated with 10cm mineral wool board

| BAMBOO CONSTRUCTION | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| bamboo (length:6m, diameter: 15cm) | 364 | unit | 40000 | 14560000 |
| bamboo tightener (ijuk) | 364 | unit | 20000 | 7280000 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 26172750 |
| | | | total price of wall per m2 | 80038.99 |
| | | | Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | 189263.3 |
| | | | total price of wall + roof per m2 | 269302.3~ **IDR 269,350.00** |

5. **plastered brick + white painted zinc roof insulated with 10cm mineral wool board**

| BRICK WORK | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| brick | 17880 | units | 600 | 10728000 |
| cement | 378 | packs | 37000 | 13986000 |
| sand | 38.5 | m3 | 114600 | 4412100 |
| rock | 13.6 | m3 | 456700 | 6211120 |
| iron steel 12mm | 1470 | kg | 8050 | 11833500 |
| iron steel 9mm | 102 | kg | 8100 | 826200 |
| iron steel 6mm | 86 | kg | 8100 | 696600 |
| concrete wire | 39 | kg | 19600 | 764400 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| total | | | | 53790670 |
| total price of wall per m2 | | | | 164497.5 |
| Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | | | | 189263.3 |
| total price of wall + roof per m2 | | | | 353760.8~ **IDR 353,800.00** |

6. **Double GRC insulated with 5cm mineral wool board + white painted zinc roof insulated with 10cm mineral wool board**

| DOUBLE GRC BOARDS INSULATED WITH 5 CM MINERAL WOOL BOARD | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| GRC board 4mm | 273 | pieces | 46000 | 12558000 |
| mineral wool board (120X60X0.5cm) | 455 | pieces | 55000 | 25025000 |
| timber frame | 2.4 | unit | 4889600 | 11735040 |
| nail | 3.6 | kg | 15400 | 55440 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| total | | | | 53706230 |
| total price of wall per m2 | | | | 164239.2 |
| Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | | | | 189263.3 |
| total price of wall + roof per m2 | | | | 353502.6 **IDR 353,550.00** |

## 7. Double ply wood wall + white painted zinc roof

| DOUBLE PLYWOOD SHEETS | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| plywood 4mm | 219.7 | pieces | 72000 | 15818328 |
| timber frame | 2.4 | unit | 4889600 | 11710836 |
| nail | 3.5 | kg | 15400 | 54519.08 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 31916434 |
| | | | total price of wall per m2 | 97603.77 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 134089.3~ **IDR 134,100.00** |

## 8. Double GRC wall + white painted zinc roof

| DOUBLE GRC | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| double GRC | 272.5 | pieces | 46000 | 12535000 |
| timber frame | 2.4 | unit | 4889600 | 11710836 |
| nail | 3.5 | kg | 15400 | 54519.08 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 28633106 |
| | | | total price of wall per m2 | 87563.01 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 124048.6~ **IDR 124,100.00** |

## 9. 2cm plastered bamboo+ white painted zinc roof

| PLASTERED BAMBOO | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| bamboo | 280 | units | 40000 | 11200000 |
| bamboo tightener (ijuk) | 280 | units | 20000 | 5600000 |
| cement plaster (cement) | 53.3 | packs | 37000 | 1972137 |
| cement plaster (sand) | 6.9 | m3 | 114600 | 786958.2 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 23891845 |
| | | | total price of wall per m2 | 73063.75 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 109549.3~ **IDR 109,600.00** |

## 10. Single ply wood wall + white painted zinc roof

| SINGLE PLYWOOD | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| plywood 4mm | 109.8 | pieces | 72000 | 7909164 |
| timber frame | 2.4 | unit | 4889600 | 11710836 |
| nail | 1.8 | kg | 15400 | 27259.54 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 23980010 |
| | | | total price of wall per m2 | 73333.36 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 109818.9~ **IDR 109,850.00** |

## 11. Single GRC wall + white painted zinc roof

| single GRC | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| single GRC | 136.25 | pieces | 46000 | 6267500 |
| timber frame | 2.39505 | unit | 4889600 | 11710836 |
| nail | 1.7701 | kg | 15400 | 27259.54 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 22338346 |
| | | | total price of wall per m2 | 68312.98 |
| | | | Price of white painted zinc roof per m2 | 36485.55 |
| | | | total price of wall + roof per m2 | 104798.5~ **IDR 104,800.00** |

## 12. Double ply wood wall + white painted zinc roof insulated with 10cm mineral wool board

| DOUBLE PLYWOOD SHEETS | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| plywood 4mm | 219.699 | pieces | 72000 | 15818328 |
| timber frame | 2.39505 | unit | 4889600 | 11710836 |
| nail | 3.5402 | kg | 15400 | 54519.08 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 31916434 |
| | | | total price of wall per m2 | 97603.77 |
| | | | Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | 189263.3 |
| | | | total price of wall + roof per m2 | 286867.1~ **IDR 286,900.00** |

### 13. Double GRC wall + white painted zinc roof insulated with 10cm mineral wool board

| double GRC | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| double GRC | 272.5 | pieces | 46000 | 12535000 |
| timber frame | 2.39505 | unit | 4889600 | 11710836 |
| nail | 3.5402 | kg | 15400 | 54519.08 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 28633106 |
| | | | total price of wall per m2 | 87563.01 |
| | | | Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | 189263.3 |
| | | | total price of wall + roof per m2 | 276826.3 **IDR 276,850.00** |

### 14. 2cm plastered bamboo+ white painted zinc roof insulated with 10cm mineral wool board

| plastered bamboo | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| bamboo | 280 | units | 40000 | 11200000 |
| bamboo tightener (ijuk) | 280 | units | 20000 | 5600000 |
| cement plaster (cement) | 53.301 | packs | 37000 | 1972137 |
| cement plaster (sand) | 6.867 | m3 | 114600 | 786958.2 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 23891845 |
| | | | total price of wall per m2 | 73063.75 |
| | | | Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | 189263.3 |
| | | | total price of wall + roof per m2 | 262327.1~ **IDR 262,350.00** |

### 15. Single ply wood wall + white painted zinc roof insulated with 10cm mineral wool board

| single plywood | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| plywood 4mm | 109.8495 | pieces | 72000 | 7909164 |
| timber frame | 2.39505 | unit | 4889600 | 11710836 |
| nail | 1.7701 | kg | 15400 | 27259.54 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 23980010 |
| | | | total price of wall per m2 | 73333.36 |
| | | | Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | 189263.3 |
| | | | total price of wall + roof per m2 | 262596.7~ **IDR 262,600.00** |

### 16. Single GRC wall + white painted zinc roof insulated with 10cm mineral wool board

| single GRC | estimated number of supporting material | | price per unit | total price |
|---|---|---|---|---|
| single GRC | 136.25 | pieces | 46000 | 6267500 |
| timber frame | 2.39505 | unit | 4889600 | 11710836 |
| nail | 1.7701 | kg | 15400 | 27259.54 |
| white painting | 163.5 | kg | 26500 | 4332750 |
| | | | total | 22338346 |
| | | | total price of wall per m2 | 68312.98 |
| | | | Price of white painted zinc roof insulated with 10 cm mineral wool board per m2 | 189263.3 |
| | | | | 257576.3~ **IDR 257,600.00** |

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